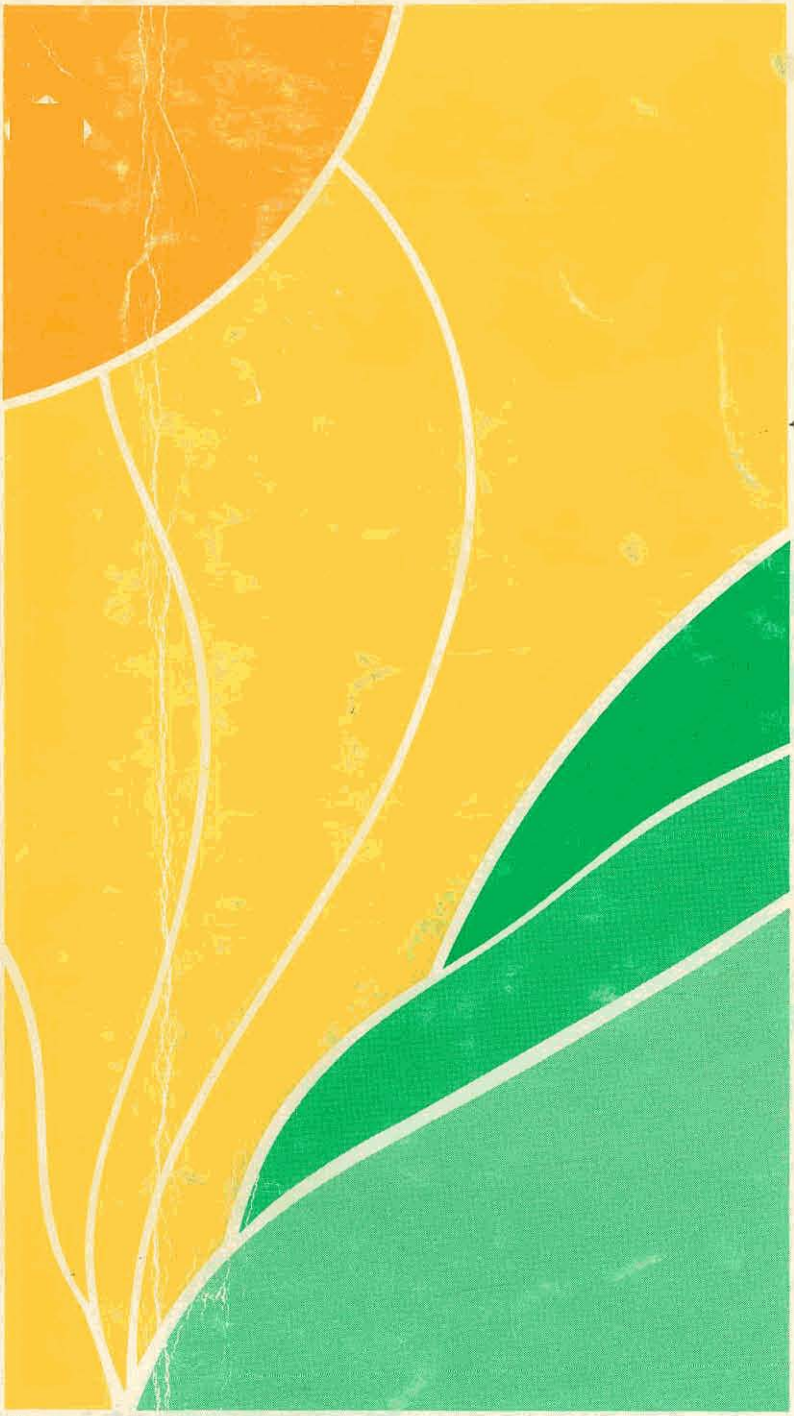


National Conference on Renewable Energy Technologies Dec. 7-11, 1980

Honolulu

Conference Proceedings

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MASTER

PROCEEDINGS

OF THE

NATIONAL CONFERENCE ON RENEWABLE ENERGY TECHNOLOGIES

DECEMBER 7-11, 1980
HONOLULU, HAWAII

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Supported
by
U.S. DEPARTMENT OF ENERGY
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by
HAWAII NATURAL ENERGY INSTITUTE
UNIVERSITY OF HAWAII AT MANOA

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NATIONAL CONFERENCE ON RENEWABLE ENERGY TECHNOLOGIES

FOREWORD

The Hawaii Natural Energy Institute (HNEI) of the University of Hawaii at Manoa welcomes the opportunity to host this major conference on renewable energy, and acknowledges with appreciation the support from the U.S. Department of Energy and the Western Solar Utilization Network in conducting the Conference.

HNEI was formally established by the Hawaii State Legislature in 1974, following energy research activity at the University on replacements for imported oil dating back into the 1960s. The 1972 State Legislature, well before the Middle East oil embargo and resulting energy shortfall, first appropriated $200,000 for research on energy alternatives, and a vigorous research, development, and demonstration (RD&D) program on Hawaii's indigenous energy resources has continued to the present day.

The primary justification for holding this National Conference at this isolated location, no matter how pleasant a spot it may be to visit in mid-winter, is in recognition of the progress made to date in Hawaii with its alternative energy RD&D programs. There is probably a higher concentration of renewable energy demonstration projects to view in Hawaii – direct solar, wind, biomass, OTEC, geothermal – than any other spot in the world. It is anticipated that the field trips to these demonstration sites, in conjunction with the broad coverage on all aspects of renewable energy at the technical sessions, will provide a comprehensive overview on both the theory and the application of renewable energy resources.

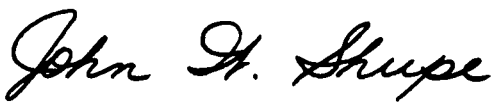
The people most responsible for pulling together the excellent papers in the eleven program categories are the Program Chairmen, whose names are listed at the beginning of each technical program. They, along with their respective USDOE Advisors, deserve our special appreciation, as do the authors who met the unreasonable deadlines to have their 227 papers or extended abstracts included in these Proceedings for distribution at Registration.

The Proceedings' format includes thirteen sections. The full papers of the Plenary Session speakers appear first, followed by the eleven Overview presentations, and then the extended abstracts for each of the eleven technical sessions. Each section has a table of contents listing the author and title of the presentation, followed by the paper or abstract in order as listed. Those authors who were unable to meet the deadline for submission of camera-ready copy are noted in the Proceedings by an asterisk, rather than a page number for their presentation.

The tentative programs as they appear in the Proceedings were in effect as of September 1, when the Proceedings were finalized. There will probably be subsequent revisions, so please refer to the Conference Program for a more recent up-date–although there may be last minute changes to it as well. All authors who are added to the program, as well as those who missed the Proceedings' deadline, will be encouraged to bring copies of their presentations to the Conference for distribution. Request for these copies should be made directly to the authors.

These Proceedings were coordinated and assembled by Administrative Assistant Mary Kamiya, with assistance from Elaine Shimabukuro and Patricia Aoyagi. Most of these papers and abstracts were printed as received as camera-ready copy; many were given minor editorial revision; a few were rewritten. We regret that there was insufficient time to check all editorial changes with the authors.

We sincerely hope that all participants will judge this to be a worthwhile Conference, and that those of you who were unable to attend but are reviewing these Proceedings will find the presentations to be both interesting and informative.



John W. Shupe
Conference Chairman

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NATIONAL CONFERENCE ON RENEWABLE ENERGY TECHNOLOGIES

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DOE: *Frederick Morse*
Regional Energy Planning: *Robert Odland*, Solar Energy Research Institute
DOE: *James Quinn and Mary Glass*

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PLENARY SESSION PRESENTATIONS

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GOVERNOR'S WELCOMING REMARKS

George R. Ariyoshi
Governor, State of Hawaii
Honolulu, Hawaii, U.S.A.

It gives me a great deal of pleasure to extend the warm aloha of the people of Hawaii to the attendees of this major Conference on Renewable Energy Technologies. Most of you have come to our island State from the Mainland United States. Others among you are from foreign countries. All of you are most welcome. May your participation be mutually beneficial to all regions and to all groups represented here today.

To those of us from Hawaii, this seems like the logical place to hold a National Conference on Renewable Energy.

- Of all 50 states, Hawaii is the most vulnerable to dislocations in the global energy market.
- We have no known fossil fuel reserves; no offshore oil.
- No coal can come into this State by rail; no natural gas by pipeline.
- The energy demand on our utilities is too small to accommodate massive power plants.
- We are not tied into a regional electric grid, so that we can share peak loads with adjacent states. In fact, our separate islands are not even interconnected into a common electric grid.

Except for the burning of bagasse -- sugarcane waste -- as boiler fuel, and a small amount of hydroelectric power, essentially all our energy -- 92 percent of it -- comes from imported oil, most of which is foreign crude. And this near-total dependence on seaborne petroleum, which with each passing Middle East crisis becomes more expensive and less secure, is a travesty. For Hawaii is blessed with a variety and abundance of indigenous energy resources, which can serve as alternatives or substitutes for imported oil: direct solar radiation, wind, biomass, geothermal, ocean thermal -- all renewable and all potentially low-polluting, when compared to coal or nuclear power.

We are actively pursuing the development of all of these renewable resources. I would like to present a brief summary this morning on the status of these programs -- many of which you will be visiting later in the week on the field trips to renewable energy demonstration sites here on Oahu and on the Neighbor Islands.

Presently we have about 14,000 solar water heaters installed on homes, businesses and institutions throughout the State. I am informed that Hawaii may have the highest per capita rate of solar collectors of all 50 states. Three projects are nearing completion for installing photovoltaic solar cells on homes on Oahu and Molokai. There is also a major solar demonstration project at the Wilcox Memorial Hospital on Kauai, where a series of parabolic troughs focuses radiation on photovoltaic cells to generate 70 kilowatts of electricity and provide enough hot water

to satisfy total hospital requirements.

The ocean itself is an excellent solar collector and storage system, and Hawai is optimistic over the potential of ocean temperature differences to provide secure, competitive base-load power. All three of our nation's current major salt water OTEC projects are located in Hawaii.

- Mini-OTEC, a joint venture of the State of Hawaii, Lockheed, Dillingham, and other business interests, has demonstrated successfully a fully operational close-cycle OTEC system. Mini-OTEC generates 50 kilowatts of energy, of which 40 kilowatts is used internally to drive the system and 10 kilowatts is the net power output.

- The Seacoast Test Facility at Ke-ahole Point is the second major OTEC project to be located in Hawaii. It is jointly funded by the U.S. Department of Energy and the State of Hawaii to provide a permanent shore-based laboratory from which to conduct reliable, economic, long-range test programs on biofouling, corrosion, materials and component performance.

- The third project is OTEC-1, the major U.S. Department of Energy effort to obtain operational data on a one-megawatt close-cycle system. OTEC-1 is deployed 15 miles off the Big Island of Hawaii, where it will obtain component performance records throughout 1981.

The Northeast trade winds that blow across Hawaii represent one of the most consistent and reliable wind patterns in the United States, and are further enhanced by the terrain of these islands. Favorable windmill sites, with average wind velocities of 20 to 24 miles per hour, are found on most of our major islands. One of DOE's 200-kilowatt wind turbine generators is presently feeding electricity into the utility grid here on Oahu, while a wide variety of smaller wind generators -- both horizontal and vertical axis -- are in operation throughout the State. Our Hawaiian Electric Company has contracted for power from 25 additional wind machines in a planned 80-megawatt system.

Geothermal energy also shows excellent potential for meeting a significant portion of Hawaii's future energy requirements. The hottest geothermal well in the world is located on the Big Island of Hawaii, and the quality of the geothermal fluid is excellent. Electricity from this well will go on line in April of 1981 to meet the energy needs of over 3,000 people. We anticipate a rapid expansion of geothermal energy -- both for electricity and for process heat -- as the nature and the extent of the resource and of the market become better defined. We are proceeding with geothermal resource assessment throughout the Big Island and on up the island chain, including Oahu. Investigation is also underway on undersea cables as a means for facilitating energy transport between islands.

The final classification of energy resource that I will mention is biomass. Presently bagasse provides nearly eight percent of the total energy requirement of the State, including over 40 percent of the electricity used on the islands of Hawaii and Kauai. Studies are underway for greater utilization of sugarcane -- and also of eucalyptus and other forest species -- as boiler fuel. Many forms of biomass, including cane, can be converted to liquid fuels, and we presently have an interesting project jointly funded by the State and the Solar Energy Research Institute on oil from algae.

So Hawaii's ultimate energy mix will probably include at least a half-dozen of our indigenous resources, each optimized to satisfy appropriate end-use demands, and all contributing to the goal of energy self-sufficiency.

Hawaii has made excellent progress to date in the research, development, and demonstration of renewable energy resources. Over the past decade, nearly $62 million has been authorized for alternate energy programs in Hawaii most of this support coming in the last three years. A major contributing factor of our success to date has been the high degree of cooperation exhibited for this endeavor by all segments of government and the private sector.

Although we are pleased with the progress made in renewable energy RD&D, as yet these programs have made very little impact on our total energy supply picture. Hawaii must move rapidly to the commercialization of its energy alternatives. We face the possibility of a more drastic series of dislocations in the global energy market in the decade ahead than was experienced over the past decade. Our present near-total dependence on imported oil provides a strong incentive to achieve energy self-sufficiency as quickly as it is technically and economically possible. And as your Conference theme suggests, we are hopeful that Hawaii and other island communities can fulfill a model or pathfinder role in demonstrating to continental land masses what can be done in the effective utilization of renewable energy resources. Thank you.

WELCOMING REMARKS

Mayor Frank F. Fasi
City and County of Honolulu

It's my pleasant duty as Mayor of the City and County of Honolulu to welcome all participants in this National Conference on Renewable Energy Technologies and the field trips which have been arranged to show the steps which we have taken in Hawaii toward energy self-sufficiency. I wish you a successful conference in every respect.

Honolulu especially welcomes the men and women who have traveled to this conference from other states and countries. When you return to your homes and businesses, we hope that you will carry back many enduring memories of Hawaii's hospitality and aloha.

All of us will count this conference as a big success if even a little progress is made toward solving the many vexing problems which face the people of the free world in regard to our over-dependence on petroleum and petroleum products. The problems are especially difficult for our state which is made up of noncontinuous islands. An alternative energy breakthrough, such as geothermal power for the Big Island, will be of little help in the forseeable future to this island of Oahu, where 81 per cent of Hawaii's population lives and works.

Your conference program lists ten separate categories of renewable energy technology, plus regional energy planning. Just a listing of the categories you will address over the next few days is enlightening and indicates the many directions which we may take in finding substitutes for petroleum.

I believe I was the first public official in Hawaii to see the energy crisis approaching. It was back in 1973, at least six months before the Middle East oil embargo, that I formed this City's Energy Resource Committee. Our attack was two pronged. The first concern was to keep essential vehicles moving -- police cars, buses, ambulances and fire trucks. The second concern was to investigate alternative sources of energy.

Our immediate investigation covered wind power, geothermal power, the burning of refuse and/or sugar cane bagasse for power, solar energy for water heating and the possibility of substituting coal for oil.

We also remembered that during World War I - in 1919 - one of the sugar plantations on Maui manufactured alcohol and used it in company trucks and automobiles -- an early form of gasohol.

My first reaction to the energy crisis was that anything I could do as Mayor would be stopgap in character; that the real initiatives lay in Washington, the Middle East and the State Department, far beyond the reach of the Mayor of Honolulu.

Now I know I was mistaken. My wife, Joyce, put me on the right track. One night she said, "Frank, turn out that light in the bathroom. I don't want to waste one more dollar on the OPEC cartel that I have to."

Members of the Fasi family soon discovered that they were wasting a great deal of electricity without realizing it. We worked at it and cut our electric bill about 20 per cent. Carrying over this idea to City government, I was able to spearhead a drive to conserve energy.

From the first, I saw Honolulu's public bus system as a primary means for us to save on gasoline. As the price of gasoline rose, more and more people left their cars in the garage and took the bus.

Last year, ridership on our then 350-bus fleet totaled 68 million. This year, with 400 buses, we expect to transport 72 million.

It is clear, however, that as the energy crunch worsens, even 400 buses will not be able to properly service Honolulu's people. I have been a prime mover in promoting a fixed-rail, rapid transit system between Hawaii Kai and Pearl City, fed by bus lines running to all parts of Oahu. There is no doubt that such a system could materially reduce Hawaii's dependence on imported petroleum products. The Federal government has indicated deep interest in funding 80% of the cost of building such a system.

Working toward mass transit has been but one attack. Other energy savings, big and small, have been achieved by such programs as turning off unnecessary street lights and, now, replacing all of our high-energy burning street lights with low-energy, high pressure sodium lamps at a cost of 3.5 million. We estimate that the City will reduce its annual electric bill by at least $1,350,000 when this program is completed -- even more as the cost of oil-produced energy soars higher and higher.

Turning to renewable energy sources ... the City is building a plant to burn 1,800 tons of solid refuse per day. The plant will generate 35 megawatts of electricity, or about five per cent of Hawaiian Electric Company's load. Thus the plan will enable us to reduce our requirements for imported oil by 560,000 barrels a year. The plant will cost $100 million and is being funded with reimbursable bonds, paid for by the sale of electricity and recoverable metal by-products.

Also, we are studying uses for the sludge which is available at Honolulu's wastewater processing plants. The sludge can be used either for fertilizer or be burned for power.

When you take the field trip to Kahuku, you will see an experimental wind power unit. Its activation has given me a great deal of satisfaction since this Federal project was originally initiated in 1973 by my Energy Resource Committee, working with the Hawaiian Electric Company.

When I see this giant, streamlined windmill turning, it reminds me that our oil problems may be a blessing in disguise. It will take time and investment but, in the long-run, as America develops its many sources of renewable energy, our economy will be healthier, people will be more resourceful and the nation will be stronger.

I see this conference as pointing the direction toward additional attacks on freeing Honolulu from its heavy dependence on imported petroleum products. A bonus will be the reassertion of the old virtues of self-reliance, thrift and independence.

Again, welcome to our city and aloha.

MEETING THE YEAR 2000 CHALLENGE: A WESTERN SUN INTERPRETATION

Donald W. Aitken
Executive Director, Western SUN
Portland, Oregon

The President's goals for conventional energy to be displaced by renewable resources in the year 2000 set a sobering task for the Nation, but one with such demonstrable benefits that it would be irresponsible not to accept the challenge. Accomplishing these goals represents new activities across almost all economic sectors, with these activities in turn stimulating new jobs, better economic use of non-renewable resources, and investment of capital both locally and regionally to purchase goods, materials and services.

Remarkably, these benefits all accrue as bonuses from the central aim of gaining access to energy from resources that remain available in undiminished abundance even as we use them. And equally remarkable is that as we concentrate on on-site and regional applications, we collectively contribute to the national goals of a reduction in inflationary pressures, increased productivity, decreased unemployment, an improvement in our balance of payments, and diminished susceptibility to international pressures.

In short, the 20% goal represents a step that is 20% on the way toward economic and political stability and energy self sufficiency. But it also provides an opportunity to move 100% of the way into an area of renewed pride over our creative, technical and social accomplishments: we engineer energy solutions, rather than problems; our architects design building and residential energy resources, rather than users; our builders provide comfortable low budget living, rather than unaffordable dreams; and our communities strive for at least partial economic and energy independence, reversing the past trend toward ever greater dependence on a supporting central government.

Certainly one of our major challenges is to enlist full national support toward the realization of the 20% goal, beginning at the very least with a substitution of the limited view of renewable resource system benefits solely in terms of user cost paybacks by a more realistic and appropriate form of evaluating benefit and sharing costs with all beneficiaries of the transition. And it is a major regional challenge to determine a proportionate regional responsibility toward attaining the 20% goal, in view of realistic national budgeting constraints and regional climate and social realities.

The thirteen states within the Western Solar Utilization Network (Western SUN) region contain about 18% of the current U.S. population on 49% of the U.S. land mass. This might suggest that we should at least help assure that 18% of the national use of renewable energy resources be accomplished within our region. But since renewable energy resources are distributed over land and water surfaces, this might also suggest that our region should tap into 49% of the nation's renewable energy resources, and either export what we don't use (as in the case of electric energy conversion) or use more than our share of on-site solar thermal, wind and wood-resource energy, to provide greater relief of fossil fuels now being misused for low-grade thermal and marginally useful electric applications directly suitable for renewable resource substitution.

Within these broad ranges, these goals do convert to estimates of levels of activity and numbers of things -- homes, buildings, collector panels, wind generators, photovoltaic arrays and collections of supporting hardware that improve the efficiency of our use of these devices and related design techniques. For example, if the western responsibility of meeting the year-2000 goal for active solar systems were met at a commercial average cost of $\$35/ft^2$ (cost of the entire system referred to the collector), it would represent at least $166 billion of activity over the next 20 years!

In view of such staggering numbers, it is evident that no government or governmental agency can go out and buy the job. Rather, it is the collective responsibility of researchers, industry and governments to get the job started: to stimulate by example and leadership a higher degree of motivation for the accelerated commercialization of the renewable energy resources, while at the same time identifying, addressing and alleviating the technical, economic, political and educational barriers that currently impede such an accelerated pace of application. Then the public can get the job done.

Isolated research, leaving the social problems to others, will not work in the solar field. Since the aim is to accomplish the use of the renewable energy resources, the variables affecting the widespread adoption of these resources in a real world of real markets and real energy costs must shape and steer all RD&D efforts. Research and commercialization go hand-in-hand in both the national and regional energy transitions. There can be no isolated actors, any more than there can be isolated funding in the early days of moving from experiment to full public acceptance and free market dynamics.

With all of this in mind, Western SUN's programs are based on a dynamic model in which effort will always be emphasized in market-ready technologies and techniques, in locales where climatological and social conditions favor a high multiplier return for early effort, and in which all activities will be tracked from careful baseline determinations to spot and address both strong and weak program impacts. And Western SUN's regional strategy is to provide the multi-organizational and multi-agency "orchestration" needed to yield the combined effort necessary to meet the region's obligation toward fulfilling the President's goals.

For example, planned FY '81 expenditures for Western SUN are to be heaviest in the market-ready technologies, such as residential water heating and climate-responsive design for homes and buildings, with a concomitant focus on training, information and education. No less important will be Western SUN support for the Residential Conservation Service, the Energy Extension Service, and Federal Schools and Hospitals Program by providing timely technical assistance to assure the maximum use of the renewable resources in those programs.

Climate-responsive passive design techniques are addressed in space heating and cooling, with programs designed to provide successful building plans to support new construction, and to address resale market factors in retrofit applications. Retrofit residential electric generation allows Western SUN to orchestrate SWECS design tools and reformatting, using work by SERI, the National Laboratories, and state universities. In the process, this work begins to anticipate downstream photovoltaic applications in residences.

The impact of utility efforts will be tracked by Western SUN through a careful monitoring of the impact of utility involvement on solar suppliers and users in the Western SUN region, while tracking closely the useful programs now being developed and implemented by the Electric Power Research Institute (EPRI). Commercial heating

and cooling will be stimulated in part by an analysis of the potential for renewable energy equipment leasing, a recommendation given high priority by Western SUN's industrial advisory panel.

These are but a few of the activities Western SUN expects to accomplish in FY '81 alone. More importantly, though, in the process of carrying out these activities Western SUN will be contributing its part--by example with its own downtown solar-converted office spaces, and by leadership with its state-focused programs--both toward the desired 20% goal in the substitution of renewable resources for depletable ones and toward the goal of combining a renewed vision of the possible with a revitalized surge of public and professional contributions toward making the desirable and the possible become the norm. We <u>can</u> do it!

CONFERENCE GOALS AND OVERVIEW

John W. Shupe
Energy Research Coordinator
University of Hawaii at Manoa
Honolulu, Hawaii

Before presenting a summary of the Conference goals and objectives, I would like to give a brief overview of what you may expect in the week ahead and make a few acknowledgments.

The Department of Energy and Western SUN have already been recognized for their moral and financial support of the Conference. The next group to be acknowledged is the Steering Committee, whose names are listed in your Program, and which met three times to assist in the development of overall policy and guidelines. The Honolulu Coordinating Committee and the Local Liaison Group, also listed in your Program, provided just that--coordination and liaison for local arrangements and logistics, particularly for the field trips to energy demonstration projects. To the 39 individuals serving on these three groups--some of you in a dual capacity--a heartfelt mahalo, our Hawaiian word for "thank you".

The people most responsible for pulling together the excellent papers in the eleven program categories, are the Program Chairmen, whose names are listed at the beginning of each technical program. In most cases these Chairmen were ably assisted by their DOE Program Advisors, and it's this group of 22 Program Chairmen and Advisors which merits our special appreciation for what looks like an outstanding program. Our appreciation also is directed to the more than 300 speakers and session chairmen for their collective contribution to the Conference.

We will continue to meet for the rest of the day here in this ballroom as a single group--except for the luncheon break at the adjacent Royal Hawaiian Hotel, where we will hear Denis Hayes' address. Beginning tomorrow morning, however, we will split into nine concurrent sessions, covering the eleven program categories.

The logistics for planning and implementing this nine-ring circus of technical sessions and related field trips have been formidable. Overall responsibility for conducting the Conference lies with HNEI, the Hawaii Natural Energy Institute of the University of Hawaii at Manoa, and at this time, I would like to introduce Dr. Paul Yuen, Director of HNEI. Paul will be presiding at the Conference banquet Tuesday evening, so you will have the opportunity to hear from him at that time.

Directly responsible for seeing that everything runs smoothly is our personable and efficient Conference Coordinator, Ms. Lynn Ibara. If you have any questions or problems that arise during the next four days, please direct your inquiry to anyone wearing the blue and gold identification buttons of the type that Paul, Lynn, and I are wearing. These people will be HNEI or Conference staff and should be able to respond to your questions.

The focus of this Conference is on renewable energy resources and their role in the future energy supply picture. I would feel remiss, however, if we did not acknowledge early in this Conference the importance of conservation in attacking the demand side of the energy equation. It is essential that effective conservation measures be established and implemented for all areas of energy utilization,

particularly in the United States with its excessive per capita consumption of energy. The potential of effective conservation measures for decreasing oil imports to this nation could easily exceed the near-term impact of all of the renewable resources. But even with a strong conservation effort by the industrialized countries, there will continue to be a relentless increase in the global energy demand. Energy has fast become the basic world commodity. A secured energy source is vital to the economic well-being and the political stability of every nation. In addition, social and economic advances in the developing countries of the world will come about only with massive increases in energy utilization.

And where is all this energy coming from? General consensus appears to be emerging that eventually renewable energy resources will provide a major share of this total energy demand, but there is little agreement on the timing and the level of this replacement. Much of the "accepted conventional wisdom" still views the renewables as exotic 21st Century technologies, and projects the same 60-year penetration cycle for these resources as experienced first by coal and then by oil.

By contrast, in Hawaii we feel that a combination of political, socio-economic, and environmental factors--some international in scope, others national and local--will greatly accelerate the rate of penetration of renewable resources into the energy market, and that they should begin to have a significant impact on our island economy by the end of this decade. We welcome the opportunity to host this Conference, and feel that the visibility and interest generated by your presence here will help reinforce our efforts toward commercialization of Hawaii's indigenous energy resources. In addition we are hopeful that holding the Conference in Hawaii, where a friendly environment--both physical and institutional--exists for the development of indigenous resources, will have a positive impact on the prevailing attitude toward the viability of renewable energy that will extend far beyond these island shores.

The Conference program has been developed not only to provide an up-date of the most recent progress in the technology for the development of the various renewable resources, but also to cover their application and commercialization as well. Many of the environmental, financial, legal and regulatory problems are common to a number of the renewable technologies. The Conference format is intended to provide a high degree of interaction among the various technologies, which should broaden perspectives and encourage a systems approach in evaluating the role of renewable resources in regional energy planning.

To assist those of you who may have general interest in any or all of the renewables obtain a better understanding of the status and potential of each of these technologies, we have established a series of comprehensive overview presentations. These eleven key presentations are all scheduled here in this ballroom at 8:30 and 11 AM, and at 1:30 and 4 PM. Knowledgeable, able speakers have been selected to provide these state-of-the art summaries for each of the renewable technologies, and this lecture series should be one of the Conference highlights. Details on these overview presentations are listed in your Conference Program.

In conclusion, I would like to emphasize again the pleasure, the pride, the excitement which those of us from Hawaii experience in hosting this Conference. One reason is that we have a concern that the feeling which still prevails among many of the energy planners and managers that the renewable resources are far out and far off 21st Century technologies is another one of those prophecies which tends to be self-fulfilling; for without adequate support, incentives, and encouragement, the renewables could make only minimal penetration during the next two decades.

As you have heard from Governor Ariyoshi, Hawaii has made excellent progress with its RD&D programs, and a number of the renewables already are either providing cost-competitive energy or are approaching commercialization. This island State still has a long way to go to be energy self-sufficient, but we'll get there. The progress that Hawaii makes in achieving this goal should help dispel the myth that renewable energy resources are 21st Century technologies, and should strengthen the world-wide resolve to make more timely and effective use of alternatives to imported oil. May this Conference lead to that objective.

THE ATTAINMENT OF RENEWABLE ENERGY SELF-SUFFICIENCY

KEYNOTE ADDRESS BY U.S. SENATOR SPARK MATSUNAGA
AT THE
RENEWABLE ENERGY CONFERENCE
HONOLULU, HAWAII
Monday, December 8, 1980

Today is a most significant day not only for Hawaii, but also for the Nation as a whole, for we are commemorating both the culmination and commencement of a necessary crusade to hasten the attainment of renewable energy self-sufficiency. The culmination is in the realization by responsible leaders in government and the private sector that something positive and dramatic must be done and done immediately to cope with our energy crisis. As a consequence, an unprecedented degree of planning together among Federal, State and local officials, as well as representatives of private industry, has taken place in recent years.

The commencement is in the implementation of plans drawn up in the initial phase.

The significance of this day lies in the probability that renewable energy alternatives may well turn out to be the only long-term solution to our seriously worsening energy crisis. This very first Department of Energy conference, in its effort to integrate all of the renewable energy technologies, may therefore be remembered as the day it all began.

Why do I believe that the development of our natural energy options is of the utmost importance, and why is time of the essence? I will answer these questions as best I can, follow with an analysis of the various energy measures passed by Congress, and close with some speculations on what can be expected in the future.

We need to develop our indigenous renewable energy alternatives because our country and the World are running out of oil. Admittedly, the United States is the Saudi Arabia of coal, and it has ample supplies of oil shale. With the breeder reactor, we also have enough uranium to last for many thousands of years.

However, conversion to these alternatives will not be a simple matter--and it will not be cheap. Interestingly enough, these very same arguments are used against the renewable alternatives. Some detractors have stated that windpower technology will not become cost competitive until the mid-80's, solar photovoltaics until the late-80's and ocean thermal energy conversion until the 90's. The time scale for synfuel plants and a commercially operating breeder reactor is projected into an uncertain future.

If time was removed as a factor, I believe that the renewable energy alternatives provide the most prudent path to a sensible energy future, and the overriding reason is that the environmental consequences of nuclear energy and the fossil fuels can be disastrous.

With respect to nuclear energy, I have, on a number of occasions, asked energy officials and industry representatives if they truly believe that we now possess th technology to store nuclear wastes safely. The answers I have received have been

totally unsatisfactory.

Scientists tell us that plutonium has a half-life of nearly 25,000 years, which means that 25,000 years from now, half of the dangerous radioactive plutonium would still be there. This is an extremely long period of time. Mankind took 25,000 years to progress from painting in caves to Picasso.

For many of us, it is difficult to visualize the world in the year 2000. I can't imagine what our world will be like in the year 3000. Twenty-five thousand years from today will be the year 26,980. And in point of fact, a storage system capable of safely holding the dangerous radioactive contaminants for thousands of years will still be required.

Even if an acceptable nuclear waste storage method is developed, a second vital question is, where will the wastes be stored? State governments are becoming more and more restive about storage of hazardous materials in their own backyard. The Senate recently passed legislation which gives states veto power over federal nuclear waste storage plans. The Pacific islanders have suffered enough from earlier nuclear tests and certainly ought not be sewaged with the wastes of others. In this connection, it appears that due to the protests filed by the Pacific island governments and members of the Hawaii Congressional delegation, federal planners are now looking to the possibility of burying nuclear wastes in the non-U.S. territorial ocean bottom--again in the Pacific.

Ocean storage of nuclear wastes could be the most perilous plan of all, for the corrosive and dynamic environment could, over time, cause leakage and dispersal to populated regions. In recognition of this potential danger, the Senate Committee on Energy and Natural Resources, of which I am a member, is pledged to conduct extensive hearings on any such plan before it is implemented.

It may interest you to know that only about five months ago, the Boeing Company was awarded a $296,000 contract to investigate the possibility of exercising the so-called "space option" for ridding the earth of nuclear wastes. The energy costs will in itself be quite high, but worse yet, what if the spaceship crashed on take-off?

The March 1979 accident at Three Mile Island has been referred to by nuclear industry proponents as a relatively "minor" mishap hardly worth the media attention which it received. To those who are tempted to agree, I would point out that the recommissioning and return-to-service costs alone will approach half a billion dollars. If what happened at Three Mile Island was a "minor incident," I fear the day when a "major accident" happens.

The chances of a "major accident" happening can be gauged by the existence today of more than 200 nuclear powerplants operating commercially in 22 countries. Three hundred more are under construction or on order. The additional 300 new nuclear powerplants would quadruple the nuclear power capacity, but necessarily create greater problems of accidents and radio active waste disposal.

In a related matter, it was most unsettling to learn that the prestigious International Nuclear Fuel Cycle Evaluation released earlier this year reported

that there is no proliferation-proof nuclear fuel cycle. Five hundred and nineteen experts from 66 countries concluded that there were serious proliferation risks associated with nuclear fission, shattering the myth that nuclear power may be produced without any concern for nuclear weapons as possible by-products.

All this is not to say that I am totally opposed to nuclear energy in any form. Nuclear fusion, the process used by our Sun, has tremendous possibilities. The nuclear wastes from fusion will be of smaller quantity and will have much shorter half-lives. Not only is the fuel resource practically limitless, but it might some day even be possible for us to extract the necessary hydrogen isotopes from the sea. Because experts have forecast that a commercial fusion powerplant could be as much as twenty to forty years away, I have co-sponsored a bill which would accelerate the development of this technology.

The second option is our vast resource of coal and oil shale. The President, earlier this year, signed into law the Energy Security Act, which has a production goal of 2 million barrels of synthetic fuel per day by 1992. Sadly, this amount is only 10 percent of the petroleum currently consumed in the United States, and a quarter of that which is imported. The contention, though, is that the projected $88 billion program will serve as a stimulus for a serious run at energy self-sufficiency around the turn of the century. For those who question the sensibility of spending so much money on so little, let me remind you that our Nation will in 1980 alone import over $90 billion of petroleum.

The question we should ask ourselves is--should these public funds be spent instead on renewable energy options? An increasing number of Americans would respond in the affirmative, particularly when the environmental impact of synthetic fuels is considered.

The most fearsome of these consequences could be the effect of carbon dioxide, a seemingly innocuous gas that is the fourth most abundant compound in our atmosphere. As explained to me, all fossil fuels which are burned in air produce carbon dioxide and heat. The carbon dioxide can be analogized to the windows of an automobile. Sunlight penetrates the glass and is partially converted to heat, which is a form of energy that cannot escape from the enclosed car. The temperature inside the car thus rises. I'm sure you have all experienced the phenomenon of entering a car in the middle of a sunny day, finding the temperature much hotter inside the car than out. This is called the greenhouse effect, a principle used in cold weather regions to grow tropical plants. Accumulation of carbon dioxide in the atmosphere produces the same effect, increasing the surface temperature of the earth.

The Senate Energy and Natural Resources Committee held hearings earlier this year on this potential problem. The testimonies of experts were frightening, to say the least. Senators were told that today there are 334 parts per million of carbon dioxide in our atmosphere. This carbon dioxide content is presently increasing at a rate of 1.5 parts per million each year because the world is burning more and more fossil fuels. The rate of increase is growing exponentially. One extreme, but commonly held theory, is that by the year 2005, only 25 years from today, the carbon dioxide concentration could increase by 50%, causing a 2 to 5 degree fahrenheit rise in the average temperature of our atmosphere. As early as 2030, a doubling of the carbon dioxide content could occur, with a temperature increase of as much as 9

degrees fahrenheit. If this should happen, the level of the oceans will, in time, rise by 20 feet. Can you picture the surf at Waikiki rising 20 feet?

The computer models and historical extrapolations can only suggest the possibility of a detectable climatic change. In like manner, eminent specialists are predicting a sudden and cataclysmic oil dislocation--due to causes such as a major war--before the year 2000, probably in the decade of the 80's.

The trade-offs and ironies run rampant in our energy crisis. We are dangerously dependent on an uncontrollable commodity, which is bleeding our Nation by nearly $100 billion each year; but we would face economic disaster if its availability was completely curtailed. We need to convert expeditiously to our abundant indigenous resources, which industrialists tell us must be coal, oil shale and breeder uranium; but we could face environmental ruin in the process.

Fortunately, there is a safe alternative in the accelerated commercialization of the in-situ fossil fuel technologies. In-situ coal gasification, a process involving the drilling of deep holes into unminable coal seams, and converting coal into synthetic natural gas, or upgraded liquid fuel, by controlled oxidation, could by itself add a resource base, which could produce TWICE the energy equivalent of the world's recoverable oil. Because the entire process occurs deep underground, in-situ coal gasification offers the added attraction of being environmentally cleaner than other fossil fuel options. But alas, even this very cleanest of the fossil alternatives poses the problem of carbon dioxide emission into the atmosphere.

Where are we, then, if nuclear energy is presently too dangerous to use, and fossil fuels are equally dangerous in the long-term? With the indulgence of those who have heard me before, I wish to keynote this Conference by accentuating my contention that Hawaii, the Nation and the World must move towards the use of renewable energy resources, not only in the long-term, but as soon as possible. The time factor is extremely important because once the industrial wheels of progress switch to coal and nuclear energy, the business inclination to protect investments and the human tendency to resist change, will make it most difficult to convert to renewable resources.

To a large degree, the direction in which our Country will go will be determined by our Nation's lawmakers. So let me summarize the various energy measures passed by Congress and signed into law by the President in recent years. I will mainly emphasize the renewable energy character of these laws.

The 95th Congress, after nearly a year and a half of deliberation, on October 15, 1978 passed the Nation's first comprehensive energy program. It actually consisted of a package of five separate bills: (1) the National Energy Conservation Policy Act (NECPA), (2) the Powerplant and Industrial Fuel Use Act (PIFUA), (3) the Public Utilities Regulatory Policy Act (PURPA), (4) the Natural Gas Policy Act and (5) the Energy Tax Act.

Since the various program initiatives under these new laws have been in operation for less than two years, it is very difficult to gauge their progress, but in a nutshell:

1. The National Energy Conservation Policy Act (NECPA) has met with at

least limited success,
2. The Powerplant and Industrial Fuel Use Act (PIFUA) has met with almost no success,
3. The Public Utilities Regulatory Policy Act (PURPA) shows great promise of encouraging the commercialization of the various renewable technologies, and
4. The Natural Gas Policy Act and the Energy Tax Act have had mixed success.

The 96th Congress, earlier this year, followed up with the enactment of the Windfall Profit Tax Act and the Energy Security Act. The Windfall Profit Tax Act will raise $227 billion over the next decade through an oil production excise tax. During the same period, it is expected that residential energy investment tax credits will amount to $600 million; business energy investment tax credits, $6 billion; tax breaks for alternative energy producers, $160 million, and alcohol fuels producers, $1.6 billion.

With respect to residential energy tax credits, the 96th Congress raised the renewable energy tax credit rate from 22% to 40% for the first $10,000 of investment. Most of the renewable alternatives qualify, with the exception of passive solar construction, heat pumps and certain types of biomass furnaces.

On business energy tax credits, the prior law provided two types of credits: regular 10% investment tax credit and a special 10% energy tax credit. The 96th Congress upgraded the energy tax credit to 15% for solar, wind energy, OTEC and geothermal equipment purchased from 1980 to 1985, and expanded the qualification to solar process heat equipment. Hydroelectric facilities were also made eligible for an energy tax credit of up to 11 percent, with facilities producing 25 megawatts or less being entitled to the full credit. The 10% energy tax credit has been extended beyond 1982 through 1985 for equipment to burn biomass, convert biomass into synthetic solid fuel, or to burn a synthetic solid fuel derived from biomass. The 10% credit has also been extended through 1990 for certain long-term energy projects.

The alternative energy production tax credit was designed to bridge the price gap between oil and synthetic fuels. The credit was intended to protect synfuel producers from price cutting by oil producers, and therefore carried a phaseout provision when the price of oil reached $29.50 a barrel, a level which was exceeded even while the Windfall Profit Tax Act was being debated by the Senate. To encourage the production of energy alternatives for oil, the 96th Congress adopted my proposal to exempt certain processed wood and biomass products from this phaseout provision so that eligible facilities can continue to receive a tax credit of $3 for the equivalent of every barrel of oil replaced, through much of the 1980's, even though the cut-off oil price has been reached.

For alcohol fuels, the four-cents-a-gallon exemption from the Federal Motor Fuel Excise Tax has been extended through 1992. For alcohol fuel which does not qualify for the exemption, there is a tax credit of 40 cents a gallon for 190 proof or higher alcohol and 30 cents a gallon for 150 to 190 proof alcohol.

Finally, the 96th Congress provided exemptions from the tax on bonds floated to underwrite facilities for converting solid waste to steam, electricity or alcohol and facilities for generating electricity at small scale dams or for using solar,

wind or geothermal energy equipment.

The Energy Security Act, enacted in July of this year, is a monumental piece of legislation in many respects. The Act, with expected extensions, could be worth up to $100 billion dollars when completed. Fifty-three Senators and Congressmen, comprising the largest Conference Committee in the history of the Congress, worked on the bill.

The titles that deal specifically with renewable energy include the following:

Title II, The Biomass and Alcohol Fuels Act, authorizes $1.45 billion for developing crops, wastes, timber, and other assorted biomass. The United States Department of Agriculture would have jurisdiction over all projects which annually produce less than 15 million gallons a year (or about 1000 barrels a day) of synfuel from agricultural and forestry resources. The Department of Energy would oversee all other biomass projects, including fuels from aquatic plants and certain urban waste projects.

Title IV, The Renewable Energy Resources Act, establishes programs to promote local energy self-sufficiency, coordinate information dissemination and outreach programs and expand the National Energy Act to allow run-of-river hydropower projects.

Title V, The Solar Energy and Energy Conservation Act, establishes a Solar Energy and Energy Conservation Bank in the Department of Housing and Urban Development and a Residential Energy Conservation Office in the Department of Energy to supervise a $3 billion program of energy conservation.

Title VI, The Geothermal Energy Act of 1980, provides for financial assistance programs within the Department of Energy to promote exploration and confirmation of geothermal reservoirs, and provides funding for feasibility studies and construction of specific geothermal projects. The Department of Energy is also directed to conduct a study of reservoir insurance in cooperation with the insurance industry. A number of other amendments were made to ease the regulatory burdens of small geothermal plants and to provide special help for direct heat utilization projects. Language was added to amend the Geothermal Research, Development, and Demonstration Act of 1974 to qualify deep sea cables for guaranteed loans.

In addition, Title VII creates programs to study acid rain and carbon dioxide problems associated with energy production.

Two renewable technologies were purposefully excluded from the Energy Security Act, so that greater visibility could be given to promoting these options. Windpower and ocean thermal energy conversion (OTEC) were the subject of separate bills passed by the 96th Congress.

The progress of OTEC since the historical success of Mini-OTEC in August of last year has been phenomenal. Its legislative record can conveniently be measured by monthly milestones:

August 1979: Mini-OTEC proves feasibility of technology.

September 1979: The junior Senator from Hawaii introduces the first OTEC bill ever introduced, The OTEC Research, Development and Demonstration Act.

October 1979: The junior Senator from Hawaii chairs the initial hearing, held in Washington, D.C., and hosts a reception for the OTEC community, joined by 24 Senators.

November 1979: Congressman Don Fuqua of Florida introduces the House counterpart of the OTEC RD&D bill.

December 1979: Congressman Gerry Studds of Massachusetts introduces the OTEC financing and regulatory bill, followed by the Senate equivalent, introduced by Hawaii's two Senators.

January 1980: Senate passes the OTEC RD&D bill, introduced by the junior Senator from Hawaii.

May 1980: The Office of Technology hosts an OTEC workshop where convincing evidence of the technology's potential is shared.

June 1980: The House passes the OTEC RD&D Act, establishing a national goal of 10,000 megawatts by 1999.

By the end of the summer both bills were signed by President Carter, the S.S. Ocean Energy Converter was dedicated and the much awaited Program Opportunity Notice for the 10/40 megawatt program was released.

The Wind Energy Research, Development and Demonstration Act did not have the drama of the OTEC bill, but during this decade should have a greater impact on reducing oil imports. The eight year cost of this Act is estimated to be $891 million, with an expected authorization of $100 million in Fiscal Year 1981 and $173 million in Fiscal Year 1982. The 1982 authorization would be nearly triple the amount spent this year.

Windpower, according to the Domestic Policy Review on Solar Energy, has the potential of generating 20,000 megawatts by the year 2000. The commercialization of this technology will of course be pioneered in Hawaii, where I expect at least one wind farm of 80 megawatts to be producing full power within a few years.

Some have referred to this wind bill as the Hawaii Wind Farm Initiation Act. It is true that the 75% loan provision, of which up to 25% of the capital cost may be spent on undersea cables, will assist windpower in Hawaii. I must point out, however, that if Hawaiian wind farms can create a sufficient market for the production of wind machines, the rest of the country will be able to take advantage of the lowered costs brought about by their mass production.

The stage has thus been set for a serious attempt at the attainment of renewable energy self-sufficiency, and the State of Hawaii has taken the first major step towards implementation by submitting a $20 million renewable energy self-sufficiency proposal to the U.S. Department of Energy. This was done in August 1980, when the governor of Hawaii made a personal presentation to the

Under Secretary of Energy.

Top priority in the state's proposal is assigned to the goal of reaching electrical self-sufficiency on the Island of Molokai by the end of 1983. This would mean that the "Friendly Isle" will be going from 100 percent dependence on imported oil to total electrical independence in only three years. By this accomplishment Molokai could well provide what this nation sorely needs--a working symbol for energy independence.

Electrical self-sufficiency achieved on Molokai in 1983, could well lead to statewide electrical self-sufficiency by 1990, and net energy self-sufficiency by the turn of the century. These are monumental goals which the traditionally conservative would quickly deride as being impossible to attain. But then, who would have guessed in 1972 that the price of oil would escalate by a factor of ten in eight years. Only three years ago the conventional thinking discounted wind farms and OTEC plantships as having not even a ghost of a chance of commercial viability. Dramatic changes in circumstances call for dramatic action to meet new challenges.

National energy self-sufficiency can be attained by development of indigenous renewable resources. This can be accomplished on a sector by sector development of the resources available within each sector. We can begin here in the 50th state where 94 percent of its energy needs are still being imported in the form of foreign oil.

In conclusion, although the short term might look gloomy, I feel confident that the renewable energy technologies hold the key for a cleaner and more secure energy future. Your presence here today gives testimony to the promise this alternative holds. If Hawaii can attain renewable energy self-sufficiency in an early time frame, this accomplishment will signal to the Nation and World that it can be done. To a degree I have done my job.....I today transfer much of the remaining task to you.

RENEWABLE RESOURCE PROGRAMS

Rudolph A. Black
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Renewable energy sources include a spectrum of technologies which range from those currently ready for commercial development to those which are currently in the R&D stage with commercial development targeted for the next decade. Two renewable energy sources which are currently ready for widespread commercialization are geothermal-hydrothermal resources and small-scale hydroelectric. This overview addresses these two resource development programs of the Department of Energy and a related program in electrical energy systems, which although not an energy source in itself, is an indispensable part of development efforts to utilize renewable and distributed energy resources for electric power production. Overview papers on each of these three program areas are scheduled for presentation later in the Conference. These remarks will mention only a few of the highlights of these activities.

The geothermal program of the Department of Energy has the following three major objectives:

1) to accelerate the commercial development of our hydrothermal resources for electric power production and for direct heat applications;

2) to determine the resource base and assess the technical and economic feasibility of extracting methane from our very large geopressured resources along with beneficial use of the hot brines; and

3) to determine by the mid-1980's the technical and economic feasibility of extracting electric power and thermal energy from hot dry rock.

The hydrothermal resources include both dry steam and water-dominated systems and both are now being exploited commercially in the United States and 12 other countries. Geopressured resources consist of water and dissolved methane in deep sedimentary basins, and the economics of methane and heat extraction are being determined by Department of Energy-funded drilling and testing projects in Texas and Louisiana. Hot dry rock resources are formations at depths with abnormally high heat content but little or no water. The feasibility and economics of extraction of heat from hot dry rock is under active development in the United States at a site in New Mexico with support from the Federal Republic of Germany.

Key activities in the development of geothermal-hydrothermal electric power applications include construction of a 50 MWe flash steam demonstration plant in New Mexico, cost-shared with industry; negotiations which are underway for a 50 MWe binary power plant in California; construction of a 5 MWe binary power plant at Raft River, Idaho; testing of a 1 MWe helical screw expander in conjunction with the International Energy Agency; construction of a 3 MWe wellhead generating plant

in Hawaii; and a number of supporting activities including development and testing of direct contact heat exchangers, drill bits, logging equipment and research on well stimulation, materials, and fluid handling techniques.

Development of geothermal resources for direct heat applications has included cost-sharing of 22 demonstration projects including district heating systems, space heating applications, and industrial and agricultural process heat applications. Cost-shared economic and technical feasibility studies have been conducted for more than 42 projects proposed by potential developers at specific geothermal sites.

Currently developed hydropower capacity in the United States totals about 11 percent of the total United States electric generating capacity, however only 3 GW or 5 percent of the hydroelectric power is produced at small-scale sites (<15 MW). The undeveloped hydroelectric resources of the Nation represent an important energy source nearly as large as the total current generating capacity but increasing concerns about the potential environmental impacts of major hydroelectric facilities, land use issues, and the fact that many of the currently undeveloped large-scale resources are in areas remote from major power markets limits future large-scale development.

Small-scale hydro sites are likely to have less objectionable environmental impacts, pose fewer land use problems, and there are a large number of existing small dams in or near populated areas which are now attractive for renovation for power generation. More than 6,000 existing dams have been identified in the United States for new hydro development. The Department of Energy's small hydro program is designed to encourage non-Federal development of small hydroelectric power in connection with existing dams which are not now being used to generate electricity. The small hydro technology is mature and proven and the main barriers to redevelopment in the United States are lack of information on methods and benefits of retrofitting dams for power generation, difficulty in obtaining risk capital, and institutional and environmental constraints.

The Federal program consists of funding of 22 cost-shared projects to demonstrate economic and technical viability of small hydroelectric projects and to stimulate demand for equipment; a low-interest forgivable loan program for feasibility studies and licensing expenses; an extensive public awareness and outreach program; technical assistance to lessen institutional constraints at the Federal and state level; funding of an engineering development program to test ultra-low-head devices, test the use of siphons to replace penstocks, and determine the feasibility of using low cost pumps as turbines.

There is a need in considering the development of renewable resources for electric power generation to keep in mind the ultimate integration of such systems into the Nation's electrical network. The Department of Energy's Electric Energy Systems (EES) program has as its mission the development of options for the Nation's future electric network.

The role of the EES research is to help ensure that economic, reliable options, including equipment and system designs are available to merge future renewable resource energy generation and storage into the existing national electric network. As the electric energy generation mix changes from only control plant sources to dispersed and often intermittent sources, and as various new means to store electric energy become prevalent, the character of the electric network must undergo a substantial metamorphosis. These new devices, because they are dispersed and intermittent will require new operating strategies for electric utilities; new means to protect the dispersed devices and the system; new ways to control load

and energy sources; new agreements for ownership, rates, source management; and new system designs.

Renewable source generating devices will often be located near the customer load, or at substations, shopping centers, industrial plants, and other random sites. The common joining factor is the electric system to which they are connected. Therefore, the electric system and the new generating devices will have to adjust to accommodate this radical change. In addition these sources, many being weather dependent, may need to have their economic viability improved with the addition of storage devices. This adds another set of conditions since a new range of random sites as well as size and cost options will be introduced.

The future electric system, therefore, will be different and nontraditional. The ultimate customer, individual or utility, is interested in two key points: reliability of their energy sources, and the cost of those sources. The successful integration of the dispersed, intermittent generation sources on the Nation's electric network is extremely important if satisfaction is to be reached for the customer and the utility. This integration will not happen by chance. It must be carefully orchestrated.

Renewable energy sources are one of our brightest hopes for a better energy future. The technical sessions to follow will give us a wealth of information about these prospects and I look forward to a most interesting and productive Conference.

OVERVIEW OF NASA ENERGY PROGRAMS

Donald A. Beattie
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National Aeronautics and Space Administration
Washington, DC, U.S.A.

The OPEC oil embargo of 1973-74, provided a vivid example of this Nation's growing energy problems. The awareness of these problems sparked major changes in many federal agencies. At NASA, these changes resulted in 1974 in the creation of the Office of Energy Programs to coordinate NASA support to federal agencies responsible for energy research and development and thereby assure the effective use of NASA aeronautics and space technologies. Congress, during this period, also recognized NASA expertise and passed legislation calling for specific contributions from the Agency. Examples of this legislation include:

- Solar Heating and Cooling Demonstration Act of 1974.
- Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976.
- Automotive Propulsion Research and Development Act of 1978.

In the ensuing years, NASA's role in energy R&D has grown with the result that, today, NASA is making major contributions toward solving many pressing energy problems. At present, NASA is supporting not only DOE, but also AID, BuMines, TVA, EPRI, the Water and Power Resources Service of DOI and other organizations. The broad scope of NASA's expanding role is shown below:

MAJOR REIMBURSABLE ENERGY PROGRAMS

SOLAR TERRESTRIAL SYSTEMS
- Wind Energy
- Photovoltaic Conversion
- Solar Heating and Cooling
- Energy Storage-Redox
- High Temperature Thermal Systems

CONSERVATION AND FOSSIL ENERGY SYSTEMS
- Advanced Automotive Propulsion
- Phosphoric Acid Fuel Cell Systems
- Coal-Fired Magnetohydrodynamic Generators
- Electric and Hybrid Vehicles
- Industrial Gas Turbines

SPACE UTILIZATION SYSTEMS
- Solar Power Satellite
- Isolation of Nuclear Waste in Space

At present, the funding transferred to NASA to manage these and other projects amounts to almost $250 million per year.

THE SOLAR PROSPECT

Denis Hayes
Director, Solar Energy Research Institute
Golden, Colorado, U.S.A.

For most of human history, it was possible to speak of the future with a high degree of confidence. A person who went off one day on a flying saucer and returned to the planet a few hundred years later would not have been dazzled by a host of fundamental changes.

Such is no longer the case. Today we cannot speak with certainty about even a 20-year interval. Efforts to forecast population trends, economic growth rates, and energy usage levels have all grown increasingly sophisticated. Yet the range of opinions among recognized experts is probably broader than the range of opinions among the lay public. Nowhere is this more true than with regard to energy.

Energy forecasts are judgments made today about tomorrow, using data gathered yesterday. If the smooth flow from yesterday to tomorrow is disrupted, the projections will likely prove erroneous. The Arab embargo, the Iranian shutdown, the Three Mile Island were painful disruptions. And like labor pains, such crises are likely to grow more intense and more frequent before the birth of a post-petroleum era.

That we are coming to the end of the oil age is beyond serious dispute. Yet few people have truly come to terms with what this will likely mean for our way of life. To a far greater extent than is generally appreciated, America -- including Hawaii, at least for a while longer -- runs on oil. Most people who come to Hawaii arrive on jet planes that burn kerosene. Most personal transportation is in automobiles that burn gasoline. The cars' petroleum-derived tires roll along roads made of asphalt. The cars' lubricants, seat covers, plastic trim, hoses, antifreeze, wiring sheaths, floor mats -- all were made from oil. When carried through to other aspects of life, this implies a higher degree of dependence than can be accepted with equanimity now that our oil is running out. The long, thin lines of oil tankers that move black liquid through the world's arteries of commerce originate mostly in unstable areas. Four-fifths of internationally traded oil comes from countries in which a single assassin's bullet or a coup d'etat could cause a fundamental shift in government.

A central goal of American energy policy is to reduce our reliance on foreign oil. Since domestic oil production continues to decline, this means we seek to steadily reduce our dependence on all petroleum. The consequences -- for the environment, for the distribution of power, for the shape of our buildings and of our cities, for the transportation and communications sectors -- will likely be far-reaching. It will, almost inevitably, begin to reverse the processes of centralization that have dominated the last three decades. As we survey the options available to us, it would be wise to evaluate such indirect effects as well as the simple technical and economic parameters of our choices. Most energy choices, unfortunately, are made as though competing sources were neutral and interchangeable. As defined by most experts, the task at hand is simply to obtain enough energy to meet projected demands at as low a cost as possible. Choices swing on small differences in the perceived marginal costs of competing sources.

But energy sources are not neutral and interchangeable. Some energy sources are necessarily centralized because of engineering efficiencies possible with increased scale; others are necessarily dispersed because of the dispersed nature of the resource. Some are exceedingly vulnerable; others are almost impossible to disrupt. Some produce many new jobs; others reduce the number of people employed. Some tend to diminish the gap between rich and poor; others accentuate it. Some inherently dangerous energy sources can be permitted widespread growth only under authoritarian regimes; others can lead to nothing more dangerous than a leaky roof. Some sources can be comprehended only by the world's most elite technicians; others can be assembled in remote Third World villages using local labor and indigenous materials. Over time, such considerations may prove weightier than the financial criteria that dominate and limit current energy thinking.

Appropriate energy sources are necessary, though not sufficient, for the realization of important social and political goals. The kind of world that could develop around energy sources that are efficient, renewable, decentralized, simple, and safe cannot be fully visualized from our present vantage point. Indeed, one of the most attractive promises of such sources is a far greater flexibility in social design than is afforded by conventional alternatives. Although energy sources may not dictate the shape of society, they do limit its range of possibilities; and decentralized sources are more compatible than centralized ones with social equity, freedom, and cultural pluralism.

In recent years, it has become clear that a solar transition is a genuine option. Our current national goal for the year 2000 is to obtain 20 percent of our energy -- directly and indirectly -- from the sun. Hawaii and California have both announced their intent to substantially exceed that target.

We are now beginning to see an increasing number of federal programs and policies favoring solar development. Among the proposals now in various stages of consideration are:

- Tax credits for individual homeowners and businesses purchasing solar and wind systems.
- The Conservation and Solar Bank, which will make funds available to individual homeowners and small business.
- Proposed credits for builders of passive homes and buyers of wood-burning appliances.
- Credit for use of solar resources in producing process heat, raising the 20 percent Investment Tax Credit to 30 percent for such applications.
- A shift in emphasis within the DOE Photovoltaics Program toward decentralized applications, with broad implications for the spending of $1.5 billion for federal procurement and application of photovoltaic cells during the next decade.
- Earmarking of $750 million by the Small Business Administration for small solar and conservation business loans.

- An alcohol program promoted by Energy Secretary Duncan calling for an annual alcohol production capacity of 500 million gallons on line by December 31, 1980. Congress has created a new Alcohol Fuels Office in DOE, funded out of windfall tax revenues.

- TVA programs to make that agency a "solar showcase." These programs include installing thousands of solar water heaters on residences in Memphis, Nashville, and in rural areas with TVA loans ranging from three percent to six percent; providing interest-free loans for wood-burning stoves; working with manufacturers of modular housing to design inexpensive passive solar prefabricated homes; and designing 11 passive homes and providing a revolving fund for construction of these homes to community development agencies, which will repay the funds.

- Proposed requirements that all federal buildings utilize solar and other life-cycle cost-effective conservation measures by 1990.

- A requirement that 100 percent of new military housing and 25 percent of new military facilities authorized each year utilize "optimizing" solar systems. This should generate $100 to $150 million annually for solar businesses.

- Creation of the Office of Small Scale Technology to encourage innovation in energy by individuals and small businesses.

- And, of course, creation of the Solar Energy Research Institute -- an 800-person, $140 million dollar enterprise located in Golden, Colorado.

While a solar transition would almost certainly improve our physical environment, renewable resource development can have its own adverse environmental impacts. Although the flow of sunlight to the planet will not be affected by the extent to which we harness it constructively, that harnessing itself will have effects. Dams will be built, wind turbines erected, biomass plantations cultivated, and large surfaces dedicated to devices to make use of sunbeams. All these activities can be undertaken either wisely or foolishly, and if foolishly, negative consequences can result.

Ironically, the largest environmental impacts associated with most solar technologies are caused by conventional fuels. For the first generation of solar equipment, conventional fuels will be used to extract, refine, and fabricate the basic materials of construction and may be used as a back-up to some solar systems. But, if the materials in this solar equipment are later recycled, and if solar resources themselves provide the energy needed to fashion new devices, these already modest environmental costs will fall further.

Solar energy sources -- wind, water, biomass, and direct sunlight -- hold formidable advantages over conventional alternatives. They add no heat to the global environment and produce no radioactive or weapons grade materials. The carbon dioxide emitted by biomass systems in equilibrium will make no net contributions to atmospheric concentrations, since green plants will capture carbon

dioxide at the same rate it is being produced. Renewable energy resources can provide energy as heat, liquid or gaseous fuels, or electricity. And they lend themselves well to production in decentralized facilities.

In the fossil fuel era, the sun has been largely ignored. No nation includes the sun in its official energy budget, even though all the other energy sources would be reduced to comparative insignificance if it were. We think we heat our homes with fossil fuels, forgetting that without the sun Hawaii would be the same temperature as Alaska. We think we get our light from electricity, forgetting that without the sun the skies would be permanently black.

Hawaii already gets more than 99 percent of its total energy from the sun. To meet the remaining human energy needs from solar resources will not be easy, but -- in the long run -- it will be easier than not doing so. The state, its elected leaders, its business leaders, and its scientific leaders, all deserve congratulations for their most recent exercise in real leadership -- leading America into the solar era.

THE FUTURE GLOBAL ROLE FOR RENEWABLE ENERGY TECHNOLOGIES

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The world runs on chemical fuels. In the rural parts of the developing world, firewood, animal dung and agricultural residues constitute the major fuel supply. Their use is resulting in accelerated destruction of large tropical forest regions, topsoil erosion and loss of agricultural productivity. In the industrialized parts of the world, high quality liquid and gaseous fuels provide the bulk of the metabolic needs. Derived from fossil fuels, their combustion is resulting in increased levels of atmospheric carbon dioxide, which in turn might precipitate problems of a global nature. At most, electricity accounts for 20 percent of energy end uses in technically advanced and prosperous regions. In rural developing areas, little electricity is available, and what there is goes primarily for agricultural pumping. In the future, transformation of the poor parts of the world to a humane environment will require more energy, most of it in the form of quality fuels. In the relatively rich and developed regions, massive amounts of fuels will continue to be required, although their use will be increasingly efficient.

While the world is not running out of energy, it is running low on the most easily and cheaply mobilized sources of quality fuels. While we will no doubt mobilize increasing amounts of coal and non-traditional (and expensive) fossil fuels, in the long term we must learn to synthesize at a vast rate high quality fuels such as hydrogen and ethanol from nuclear and solar energy sources. The present rate of primary energy use world-wide is about 8 TW; providing the 10 to 30 TW required for a livable world in the next century and beyond can be accomplished only through a mix of fission via the breeder reactor, fusion, and a mix of solar energy systems. These are the options. Unfortunately, fission is a technology which requires a level of care and capability to operate acceptably at the TW level which may not be achieved in real human societies. The inherent resilience which most renewable energy technologies exhibit when subjected to severe assault is a quality which is clearly worth a great deal. As fossil and nuclear energy systems are losing their once complete economic domination of renewables, these other aspects of renewable energy systems will begin, as I believe they already have, to assume social significance in the energy planning process.

There is no doubt that in principle solar energy can provide the world with abundant, high quality secondary energy - the fuels, electricity, heat and work required by a modern society - at a rate exceeding today's energy consumption many times over (1,2). At the same time, the use of renewables on the necessary scale will require prodigous amounts of land, materials, and capital; it will take better than a century to achieve worldwide even if everything goes well; it will impact the environment and alter social and political and institutional structures; it will be the largest technical, economic and perhaps institutional accomplishment of human society. But what will the system look like?

The components of a global energy system based on sunlight range from small, self-contained units for producing hot water and electricity to a global network of hydrogen and liquid fuel production, transport (pipelines crossing continents and tankers circling the earth) and energy storage systems.

What is especially remarkable about the use of solar energy is the richness of the architecture of the possible systems, mixing elements from local to regional to global scale harmoniously, and the regional diversity of the character of such systems. Sufficient studies have been carried out (3) over the past several years in North America, the Pacific Basin, the Middle East and Western Europe for countries and smaller regions to demonstrate both the feasibility of providing an unexpected and large share of future energy needs from regional renewable resources and the variation in system character from one region to the next. Some of the most interesting examples are for island societies such as Sardinia (4) and Hawaii (5), where dependence on imported petroleum is exagerated compared with many larger regions, and where the possibilities for use of renewable resources can be substantial.

Now that some energy technologies, such as wind turbines, active and passive solar building design and energy efficient building design are entering large scale commercial availability and use, and with others, such as solar thermal electricity, ocean thermal energy conversion, biofuels and photovoltaic conversion being developed rapidly to commercial availability, there is a special incentive for individual regions and even communities to begin exploring alternative energy futures. The increasingly turbulent world oil situation makes such explorations more and more necessary. As regional analysis and planning begin to consider the incorporation of these new energy technologies into existing energy systems and landscapes, the issues rapidly transcend technical and economic concerns, important as they are. Since social forces are already the dominant factor in determining which energy facilities (power plants, coal mines, high voltage transmission lines, dams, etc.) can be built where and when (if at all), there is new social motivation to consider the emerging alternatives of conservation and renewables. This consideration brings with it a new set of institutional, regulatory and social problems and opportunities. Who owns the wind (it's not part of the mineral rights for the land)? Who owns the geothermal heat below the land? Will we accept pumped hydrostorage facilities because they make it possible to more efficiently use wind and photovoltaics? Will we accept high voltage transmission lines bringing solar electricity from New Mexico to the Mid-West? Will we accept the inevitable damage done to local ecosystems when solar thermal power plants are built in desert regions? How will we price and tax these new energy systems? The issues are endless, the challenge important and fascinating, and the outcome somewhat unpredictable. However, the process of regional planning, all around the world - not just in the United States - will provide us with a rich set of experiences, information , knowledge, and perhaps even wisdom as we find our way into an uncharted energy future.

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(1) J. Weingart (1978). "The Helios Strategy", Tech. Forecasting and Soc. Change 12

(2) J. Weingart (1979). "Global Aspects of Sunlight as a Major Energy Source", Energy - The International Journal 4

(3) See for example the documentation in "Soft Energy Notes", published by the International Project for Soft Energy Paths, 124 Spear Street, San Francisco

(4) See A. Ketoff, "Sardinia Energy Planning", this conference (abstracts)

(5) J. Shupe and J. M. Weingart (1980). "Emerging Energy Technologies in an Island Environment: Hawaii" Ann. Rev. Energy 5; 293-333

RENEWABLES IN THE U.S. ENERGY FUTURE: HOW MUCH, HOW FAST?

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> "Our conclusion is that with a strong national commitment to accelerated solar development and use, it should be possible to derive a quarter of U.S. energy from solar by the year 2000, with the major growth occurring after 1985."
>
> U.S. Council on Environmental Quality, Solar Energy: Progress and Promise, April 1978, p. 5.

> "Because of their higher economic costs, solar energy technologies other than hydro will probably not contribute much more than 5 percent to energy supply in this century, unless there is massive government intervention in the market to penalize use of nonrenewable fuels and subsidize the use of renewable energy sources."
>
> Harvey Brooks and Edward L. Ginzton, Co-Chairmen of the Committee on Nuclear and Alternative Systems of the National Academy of Sciences, in the Committee's Final Report, Energy in Transition: 1985-2010, December 1979, p. xv.

These seemingly contradictory conclusions each stimulated feature articles and editorials in the country's largest newspapers, as have similarly variable pronouncements on the potential of renewable energy sources in several other of the major energy studies of the last three years. By now it is not only the public that is confused; most of the energy community does not know what to think, either. Have these studies all been looking at the same data? Is a quarter of the nation's energy supply from renewables by the turn of century a pipe dream or an achievable target? Does it matter?

The present paper attempts to shed some light on these questions, in four steps: (a) a brief review of the conclusions of earlier (pre-1978) investigations of the potential of renewable sources in the U.S.; (b) a comparison of the general approaches, assumptions, and findings of the major studies of this topic that have appeared in 1978, 1979, and 1980; (c) disaggregated comparison of the findings of these recent studies by type of technology (e.g., electricity generation, space and process heat and cool, fuel production); and (d) a discussion of why it does matter who turns out to be right.

Earlier Studies

A multitude of studies in the early-to-mid 1970s provided widely divergent estimates of the potential contribution of renewable energy sources to U.S. energy supplies over the next several decades (Weingart, 1979). The year-2000 estimates of the most important of these studies are summarized in Table 1. The estimates for the total contribution of renewables other than hydropower and geothermal range from .5 percent to 22 percent of the total energy supply forecasted for the year 2000. Three points can be made immediately about the differences in such figures.

Table 1. Some Pre-1978 Estimates of the Contribution of Renewables in the U.S. in the Year 2000, in Quads

Report/Forecast	Electricity from STEC, PV, wind, OTEC[9]	Space & Process Heating & Cooling	Biomass, including Wastes	Hydro	Geothermal	Total Energy Supply
NSF/NASA[1]	4.6	2.1	5.1	NE[10]	NE	177
AEC[2]-MIN	4.5	1.6	0.4	NE	NE	NE
-ACC	11.5	6.5	1.2	NE	NE	NE
FORD EPP[3]-ZEG	2	1	2	4	2	100
FEA[4]-BAU	7.8	2.3	0.7	NE	NE	180
-AI	20.3	3.5	15.0	NE	NE	180
ERDA 48[5]	2.1-4.2	5.9	6.3	NE	3.1-5.6	122-165
ERDA 49[6]	5.0	3.0	3.0	NE	3.7	150
SRI[7]-REF	0	5	1	------4------		145
-SE	1	9	5	------4------		148
-LD	0	6	1	------4------		102
WAES[8]-C1	1.5	2.4	1	4.6	3.0	124
-D7	0.5	1.2	0	3.7	1.2	115

1 National Science Foundation/National Aeronautics and Space Administration Solar Panel (Donovan et al., 1972).

2 Subpanel IX of the Atomic Energy Commission Chairman's Comprehensive Federal Research and Development Program (Eggers, 1973). MIN=Minimum Viable, ACC= Accelerated

3 Energy Policy Project of the Ford Foundation (Freeman et al., 1974). ZEG=Zero Energy Growth

4 Solar Energy Task Force of Project Independence (Federal Energy Administration, 1974). BAU=Business as Usual; AI=Accelerated Implementation

5 National Plan for Energy Research Development and Demonstration (Energy Research and Development Administration, 1975a).

6 National Solar Energy Research Development and Demonstration Program (Energy Research and Development Adminstration, 1975b).

7 Stanford Research Institute (Reuyl et al., 1977). REF=Reference case; SE=Solar Emphasis; LD=Low Demand

8 Workshop on Alternative Energy Strategies (Wilson, 1977). C1=high economic growth, coal emphasis; D7=lower economic growth, coal emphasis

9 STEC=solar thermal energy conversion, PV=photovoltaic, OTEC=ocean thermal energy conversion

10 NE=not evaluated, or not evaluated for the year 2000

First, estimates of this kind are not "predictions" about what will be the case in the year 2000, except in a highly contingent sense--that is, if certain conditions held, then the contribution from renewables would be such-and-such. More precisely, the estimates are the result of the interaction of some formal or informal "model" and a set of assumptions about the future behavior of factors the model deems relevant to future energy demand and energy-supply mix. (The "model" may involve a set of equations on paper or in a computer, or it may simply be a set of relations in the analyst's head.) Many of the differences in such estimates stem from differences in assumptions (e.g., about economic growth rate, or about the relative future costs of renewable and nonrenewable energy sources), and some stem from differences in what factors are included at all and in how these factors are integrated to reach a conclusion. To the extent that an analyst makes explicit the key assumptions and interactions behind a given estimate, the user of the analysis not only can form an opinion about the reasonableness of the estimate but also may be able to devise a strategy for altering future conditions in ways that will make the outcome more favorable. Too often, unfortunately, estimates turn out to have been influenced by assumptions that are not explicit (and sometimes not even recognized by the analyst, let alone by the user).

Second, the contribution of "renewables" in the year 2000 or any other time depends on what energy sources are included under this heading. Hydropower is clearly a renewable energy source, but some studies have not included it in their tabulations, either because it is a "conventional" technology or because it seems less obviously "solar" than, say, photovoltaic cells or direct use of sunlight for heating buildings. Whether geothermal energy should be considered "renewable" is arguable; most studies tabulate it separately, but some lump it together with hydropower. Biomass energy sometimes is not included at all and often is covered very incompletely--a situation not difficult to understand in view of the diversity of biomass forms and processes that might be used to supply energy. Popular accounts summarizing studies of the potential contribution of "solar" or "renewable" energy sources rarely are specific about what was actually included, so anyone interested in sorting out the differences must delve into the (often obscure) original reports.

Third, when estimates of the contribution of renewables are expressed as percentages of total energy supply in a given year, an apparent difference between studies may result from nothing more than divergent assumptions about the total energy supply against which this percentage is measured. A quantity of energy from renewables amounting to 20 percent of the 100 quads of total energy supply envisioned by some forecasts for the year 2000 would be only 11 percent of the 180 quads envisioned by others. There are, however, some considerations that make it more difficult in practice to achieve a given number of quads from renewables in the context of low total energy demand than in the context of high demand. Most obviously, higher demand overall implies bigger opportunities for renewables in those end-uses where they fit best (e.g., low-temperature applications of direct solar heat); if overall demand is lower, getting the same number of quads from renewables requires penetrating more difficult markets (such as higher-temperature applications). Also, low-demand futures are likely to include situations where conservation has greatly reduced markets that otherwise might be served by renewables (for example, "tight" buildings reducing the need for solar heating). Finally, the higher fractional penetration needed to yield a given number of quads in a low-growth future means greater requirements for energy

storage in the case of the intermittent renewables; at low penetration of wind or photovoltaics into an electricity grid, for example, the "back-up" inherent in the rest of the grid obviates the need for energy storage to go with these intermittent sources.

Aside from differences in the total energy demand envisioned for the year 2000 and in the categories of renewables included in the tabulations, the largest differences in the renewables estimates summarized in Table 1 derive from different assumptions about incentives. The lower estimates, such as those of the Workshop on Alternative Energy Strategies and two of the three Stanford Research Institute scenarios, result from assuming that economic forces govern choices and that most forms of renewables remain expensive compared to conventional energy sources at least until the 1990s. The higher estimates, such as those of the Atomic Energy Commission's solar subpanel and the Accelerated Implementation scenario of Project Independence, represent the analysts' judgment about maximum technically feasible implementation rates, assuming incentives in the form either of early cost breakthroughs or of policies amounting to a national commitment to renewables for reasons other than direct economic-cost advantages.

The Recent Reviews

The prospects of renewables were reviewed and re-reviewed in the flurry of energy studies that appeared in 1978, 1979, and 1980. A few of these studies (e.g., Schurr et al., 1979; Landsberg et al., 1979) refrained from offering any quantitative estimates of the contribution that renewables might be making to national energy supply at the turn of the century and beyond, but most could not resist. The results of eight of the studies that did not are summarized in Table 2.

Table 3 summarizes the approaches and main assumptions used by these studies to derive their estimates for renewables. All of the studies of course relied heavily on earlier surveys, and on the current journal and report literature treating individual sources, to obtain information on likely costs versus time and on feasible deployment rates for the technologies considered. As perusal of Table 3 will indicate, the various studies fell into three categories as concerns the methods used to fashion information of this kind into estimates of future penetration of renewables:

(1) Some relied on the judgment of a relatively small number of authors to pick figures from the range of previously published estimates, incorporating stated (and perhaps some unstated) assumptions about total energy demand, costs of competing energy sources, relative attractiveness of renewable versus other sources in respects other than direct economic cost (employment effects, environmental characteristics, national security, etc.), and the policy climate deriving from perceptions about such advantages or disadvantages. The studies by the CEQ (Council on Environmental Quality, 1978); the Harvard Business School (Stobaugh et al., 1979); Friends of the Earth/University of Wisconsin (Steinhart et al., 1979); and the Union of Concerned Scientists (Kendall et al., 1980) were of this kind.

(2) Some proceeded in essentially the same manner, but with two additions/refinements: (a) they tried to involve a larger number of specialists and/or constituencies in the process of arriving at their judgments; and

Table 2. Recent Estimates for Total Contribution of Renewables (exclusive of hydro and geothermal) in the Year 2000 and Later, in Quads

Report/Forecast	2000	2010	2020
CEQ[1]	15-25		30-65
Domestic Policy Review[2]			
Base Case	6-9		
Maximum Practical Effort	14		
Technical Limit	24		
MITRE[3]			
Reference Case	11.7		
Accelerated Level I	14.7		
Accelerated Level III	21.4		
Harvard Business School[4]	16		
CONAES[5]			
Supply Panel, Business as Usual	0.1	0.6	
Steering Committee, highest Study Scenario	3	6	
Supply Panel, Enhanced Supply	5.9	10.7	
Supply Panel, National Commitment	13.1	28.8	
Friends of the Earth[6]	1.7	3.7	6.1
Energy Information Administration[7]			
Low	5.5	7.9	12.1
High	6.3	9.1	13.1
Union of Concerned Scientists[8]			
Low Solar	6		
High Solar	24	45	61

1 Solar Energy, Progress and Promise (Council on Environmental Quality, 1978)

2 Domestic Policy Review of Solar Energy (Domestic Policy Review, 1979)

3 MITRE Corporation for the Department of Energy (Bennington et al., 1979)

4 Report of the Energy Project at the Harvard Business School (Stobaugh et al., 1979)

5 Committee on Nuclear and Alternative Energy Systems, National Academy of Sciences (Brooks et al., 1979)

6 Pathway to Energy Sufficiency: The 2050 Study (Steinhart et al., 1979)

7 Annual Report to Congress (Energy Information Administration, 1979)

8 Energy Strategies: Toward a Solar Future (Kendall et al., 1980)

Table 3. Approaches and Principal Assumptions Used by Recent Studies in Deriving Solar Estimates

Study	Approach	Qualitative Assumptions	Quantitative Assumptions
CEQ	Literature review plus analysts' judgment.	DOE price goals met where applicable. Gov't. policies favor intensified RD&D, removal of barriers, incentives beyond economic competitiveness.	Total US energy demand is 80-120 quads in 2000 and 70-140 quads in 2020.
DPR	Literature review plus "informed judgment, guided by econometric computer calculations".[1]	Base Case=present policies and programs. Maximum Practical Effort=comprehensive and aggressive gov't. iniatives. Technical Limit governed by turnover time of capital stock and maximum output of solar industries.	Total demand=95-114 quads in 2000, energy price equivalent to 25-32 1977 $ per barrel of oil.
MITRE	Regionally disaggregated computer models of market penetration, with costs of renewables and competing fuels supplied exogenously.	Reference Case=present level of national commitment; current cost goals are met; economics govern rate of acceptance. Accelerated Cases=intensified RD&D, removal of barriers, extra financial and other incentives.	Oil price to industry in 2000 is 25 1976 $/bbl. Total demand=115 quads in 2000.
Harvard	Literature review plus analysts' judgment.	Vigorous action by Federal gov't. to encourage on-site solar applications. Little contribution from "Big Solar".	Total demand=100-110 quads in 2000.
CONAES	Literature review plus judgment of participants,[2] with some reference to energy-economy computer models.[3]	Business as Usual=continuation of present policies and practices. Enhanced Supply=comprehensive energy-supply policies; agressively pursued. National Commitment=highest priority to energy supply; promising technologies deployed before they are competitive.	Main study scenarios driven by GNP-growth assumptions (2 and 3 %/yr) and energy prices (ranging from constant at 1975 values to increasing to 4x 1975 values in constant dollars). Results ranged from 64 to 188 quads total energy use in 2010.

Table 3 (continued)

Study	Approach	Qualitative Assumptions	Quantitative Assumptions
FOE	Literature review, extrapolations of selected trends, and analysts' judgment.	Significant changes in social and physical arrangements with reduced transport and manufacturing and increased emphasis on services.	Energy use falls to 53 quads in 2000 and 44 quads in 2020.
EIA	Dynamic market-equilibrium, energy-economy computer models, with costs of renewables and competing fuels supplied exogenously.	Price competitiveness largely governs penetration of renewables. Coal and nuclear fission can meet most of increased demand if cheaper than oil and renewables.	Real GNP increases 2.8%/yr post-2000. Oil prices constant post-2000 at 27 ("low price"), 43 ("mid price"), or 60 ("high price") 1979 $/bbl.
UCS	Literature review plus analysts' judgment.	Low-solar case corresponds to continuation of present policies. High-solar case requires more aggressive incentives and removal of barriers.	Per capita level of goods and services in 2000= 1.0, 1.3, and 1.6 x 1978 level in 3 scenarios. Population=1.23 x 1978 figure.

1 What computer models were used and how is unclear from the available documentation.

2 The weight given to different factors varied significantly from Solar Resource Group to Supply Panel to Steering Committee, as did the quantity of information that entered the deliberations. See text.

3 The models contained little detail about renewables and generally unfavorable assumptions about their costs.

(b) they made at least some contact with computer models, although these do not seem to have been essential to the conclusions reached. The studies by the Domestic Policy Review (1979) and the National Academy of Sciences Committee on Nuclear and Alternative Energy Systems (CONAES, cited here as Brooks, et al., 1979) were in this category.

(3) Some relied primarily on rather elaborate computer models to calculate the penetration of renewables under various assumptions. (The embodiment of one's assumptions in a computer model does not necessarily make the conclusions more objective, but it may--depending on the scrutability of the model itself--make clearer to others the process by which the conclusions were reached and therefore, the circumstances in which they might be expected to be valid.) The studies by MITRE (Bennington et al., 1979) and EIA (Energy Information Administration, 1979) were of this kind.

It is easiest and most informative to organize more detailed comparisons of the studies according to these groupings, a task to which I now turn.

GROUP 1: CEQ, Harvard, FOE, UCS

These studies have much in common. They all assume a substantial decoupling of energy growth from growth of well-being over the next twenty to forty years, so that even a very prosperous U.S. at the turn of the century would be consuming only 100-115 quads of energy per year, and less emphasis on economic growth would lead to totals in the range of 50-80 quads/yr. They all contend that the desirability and/or inevitability of low growth of energy in general--and of the use of coal, nuclear fission, and imported oil in particular--stem not so much from increased direct economic costs of such supplies as from their increasingly threatening impacts on political, social, and biogeophysical conditions and processes. (This view, which I share, is elaborated at the end of this paper. See also Holdren and Herrera, 1971; Steinhart and Steinhart, 1973; Lovins, 1976.) They all are underpinned by the view that renewables, shrewdly chosen and used in moderation, would be less threatening than nonrenewables in the most important sociopolitical and environmental dimensions. Accordingly, while they do not ignore information about the economics of the renewable sources they consider, this information is used more to assess economic attractiveness of renewables relative to one another than to try to deduce rigorously the time of onset of economic competitiveness with conventional energy supplies. The idea is that even getting into the economic "ballpark" with conventional sources will be sufficient, given the sociopolitical and environmental advantages of the renewables and the availability of policies to encourage their use on that basis. All of the studies indicate that achieving the contributions from renewables they envision will require putting such policies in place promptly and implementing them vigorously.

The notable outlier of these four studies in its quantitative estimate of the contribution of renewables at the turn of the century is that published by Friends of the Earth (Steinhart et al., 1979), which has only 1.7 out of 53 quads in 2000 delivered by renewables, exclusive of hydropower and geothermal. (These last, which are lumped together, add 3.8 quads.) This study has by far the least detailed examination of renewables of the four, and it seems to have neglected biomass almost altogether--it shows no contribution at all for biomass in 1980 and less than 0.1 quad in 2000, whereas in reality biomass already was contributing 1.8-1.9 quads per year to U.S. energy supply in 1978 (1.5-1.6 as wood and waste materials used by industry, 0.3 in wood-burning stoves) (Domestic Policy Review, 1978, p. 201; Bennington et al., 1979, p. 26). Even so, the FOE study has about 25 percent of energy supply coming from renewables (now including hydro and geothermal) in 2020 and more than 50 percent in 2050. One reason the contribution of renewables rises so late in this study is that conservation is assumed to take hold very rapidly between 1975 and 2000, saving energy that the other studies replace with renewables instead.

GROUP 2: Domestic Policy Review and CONAES

The Domestic Policy Review (DPR) and CONAES studies are as a whole more richly detailed in their treatment of renewables, and in some cases more explicit about their assumptions, than are the four studies in Group 1. This greater detail reflects the broader array of solar-energy specialists and other analysts who contributed to DPR and CONAES: DPR could draw on the apparatus of the whole federal executive branch (the participation of "over 100 officials representing more than 30 executive departments and agencies" is advertised in the Executive Summary), and the National Academy of Sciences study had the usual good access to

volunteer help from throughout the technical community. (The Solar Resource Group of CONAES had seventeen members; the Supply/Delivery Panel, whose report incorporated results from the solar group and ten others, had fourteen; and the Steering Committee, whose report integrated considerations of supply possibilities, demand, environment, and policy, numbered fourteen to sixteen. Also involved in CONAES was a full-time professional staff at the Academy, numbering about six, a modest fraction of whose time supported the renewables portion of the study.) Many of the participants in both studies could and did tap their staffs in their home institutions for technical back-up.*

Given that both DPR and CONAES represent very major efforts at review and synthesis of the prospects of renewables, drawing on substantial diversity and depth of expert opinion and analysis, it seems remarkable at first that the results convey such different impressions about the likely contribution of renewables over the next two to three decades. The Domestic Policy Review has been widely (and correctly) portrayed as bullish on renewables, envisioning a contribution of 10-20 quads (inclusive of hydropower but not geothermal) by the turn of the century. The Academy study has been represented equally widely as much more pessimistic. On closer examination, however, it turns out that the apparent gulf between the two studies is not so much the result of real differences in the opinions and assumptions in the underlying technical analyses as it is the consequence of the CONAES documents' appallingly murky and even inconsistent exposition of the implications of the underlying analysis. To explain more specifically what these deficiencies were and how they ended up in the output of a National Academy of Sciences project, it is necessary to elaborate on how the CONAES study was conducted.

The task of the study as a whole was to illuminate alternative energy futures for the U.S. to the year 2010, with some emphasis on the role of the nuclear option, that is: What might energy demand be through 2010, and how would it relate to economic growth in that period? What combinations of supply technologies could be marshalled to meet the range of demands identified, and at what economic costs? What would be the environmental and sociopolitical consequences of these alternative energy futures? What policies would be required to bring about the various possible futures, insofar as society wished to steer a deliberate course? The Steering Committee, consisting initially of sixteen members of diverse backgrounds (two later resigned), was to fashion its report on this impossibly broad topic by integrating inputs from four Panels (Demand/Conservation, Supply/Delivery, Risk/Impact, and Modeling/Synthesis), each of which in turn was to base its report to the Steering Committee on inputs from subpanels called Resource Groups. (See also Brooks and Hollander, 1979, and the Steering Committee report itself, Brooks et al., 1979.) The Solar Resource Group was one of eleven such subpanels reporting to the Supply/Delivery Panel. The total number of participants on all the panels and subpanels in the study exceeded two hundred.

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* I am not aware of figures for person-hours or dollars expended on renewables in any of the studies in Group 1 and 2, but I suspect the crude index of number of pages devoted to renewables in the resulting final reports is not too misleading as regards the level of effort: DPR, 411; CONAES, 157; UCS, 131; CEQ, 52; Harvard, 47; FOE, 8. (Technical notes and references are included in these figures. The DPR's appendices containing an interim report and the public's comments on it are not.)

Obviously, this arrangement posed some potential problems of sequencing. The Steering Committee could not sensibly write its report until it had received the reports of the Panels, which could not sensibly write their reports until they had received those of the Resource Groups. (At the same time, no group was required to accept everything in the reports submitted to it; disagreements and discrepancies might exist between the report of the Steering Committee and those of the Panels reporting to it, and between the reports of the Panels and those of their Resource Groups.) All this was to be completed in two years, between fall 1975 and the end of 1977. As it happened, the study ran for more than four years, and, even at that, the Steering Committee had to write its report with only drafts and fragments of the reports of most of its Panels in hand. Almost every part of the study, in fact, was badly behind schedule almost from the outset, in part, no doubt, because the task itself was unmanageably broad and execution along the lines contemplated simply not possible with the resources available.

The Solar Resource Group was one of the few subpanels in the study to complete its analysis on schedule, but this turned out to be a mixed blessing. The work, finished in late 1976, was only published as a finished report in 1979 (Simmons, 1979), when it was already 2 1/2 years out of date. Nor did the report provide its information in quite the form the Supply Panel eventually decided it wanted. Specifically, the Solar Group devoted much of its effort to estimating likely cost trajectories of various renewables out to 2010, and it developed estimates of market penetration based on "the action of market forces in an economic environment in which the technology under consideration is competitive" (Simmons, 1979, p. 15). This approach was consistent with the Steering Committee's initial guidance to the Supply Panel: what was wanted was estimates of how much energy could be contributed by various conventional and nonconventional energy sources, as a function of time and of the price society was willing to pay. Information in this form could have been relatively easily integrated with results from other elements of the study, partly with the help of the large energy-economic computer models being refined and used by the Synthesis/Modeling Panel.

But the Supply Panel eventually decided this cost-oriented approach was unsuitable . In the Panel's words (Davis and Culler, 1979, p. 5):

> "In the judgment of the panel, however, prices, costs, and consumption of energy sources are so greatly affected by regulation and other expressions of national policy that this approach was abandoned. The availability of an energy source is much more likely to be determined by regulatory conditions and their impacts on investments than by prices or production cost. Accordingly, the panel chose to base its estimates on a range of hypothetical 'scenarios', based on sets of assumptions about these conditions."

The three Supply Panel scenarios were characterized as follows (Davis and Culler, 1979, p. 6):

- Business as Usual - "existing attitudes, policies, and practices are extended into the future with little change"
- Enhanced Supply - "a well-balanced, comprehensive set of energy supply policies is enacted and aggressively pursued"
- National Commitment - "energy supplies are given the highest priority in allocating national resources, and calculated risks are taken in deploying promising new energy technologies before they are technically

proven and economically competitive"

Apparently this change in approach came late in the Solar Group's work, for its 87-page report contains just one 3 1/2-page section that attempts, with the appearance of an afterthought, to provide some scenarios approximately along the lines just described. Only two scenarios are supplied, rather than three, and they are denoted simply "Low" and "High".

The Solar Group's "Low" scenario is based, says its report, "on the assumption that no policy will be implemented to assist the entry of solar energy into the market, that the costs of other energy sources follow the baseline schedule of the Modeling Resource Group, and that the costs of solar energy technologies follow the estimates of the Solar Resource Group (without breakthrough in advanced technologies)" (Simmons, 1979, p. 12). The actual estimates of contributions by renewables that appear in the "Low" scenario are based on the real prices of electricity and all conventional fuels except natural gas remaining constant at their 1975 values through 2010. The real price of natural gas is assumed to nearly quadruple by 2010, which gives rise to use of 0.3 quads/yr of solar heating and 0.3 quads/yr of methane production from municipal solid waste by that time. (The scenario section of the Solar Group's report does not explain why the much higher biomass contributions estimated elsewhere in the report to be available at $2 per million Btu are not relevant here; perhaps the answer is the assumed availability of oil at $9 per barrel.) This "Low" Solar Group scenario was used without modification by the Supply Panel under its "Business as Usual" heading. In reality, its assumptions were much less favorable to penetration of renewables than actual "business as usual" in 1979, when the reports came out: instead of "no policy... to assist the entry of solar energy into the market", such policies already were in force in 1979 at the federal level (most notably in the provisions of the National Energy Act) and in many states; and instead of holding constant at 1975 levels, the real prices of oil and coal had by 1979 risen by 50 percent and by 15 percent, respectively (Energy Information Administration, 1980).

The "High" scenario of the Solar Resource Group assumes "that by 1985 a national policy decision will have been made to apply vigorous means to bring about the use of solar energy in each of its various applications" (Simmons, 1979, p. 10). The estimated contributions of renewables in 2000 and 2010 in this scenario correspond closely to those derived elsewhere in the Resource Group's report on the assumption of economic competitiveness with conventional sources throughout the study's 1985-2010 time frame. (Thus, in effect, it was assumed that the policies producing this scenario have the effect of exactly compensating for any actual cost disadvantages of renewables compared to conventional sources.) These contributions, totalling 13 quads in 2000 and 29 quads in 2010, exclusive of hydro and geothermal, do not represent a summation of the maximum figures the report indicates might be technically achievable from each technology: the "High" scenario has no contribution at all from photovoltaics or from OTEC (on grounds that these, if attractive enough, would replace solar-thermal-electric or wind power rather than adding to the total); it has no contribution from terrestrial or marine biomass farming (no grounds given, although the Risk/Impact Panel expressed concern about ecosystem impacts of these technologies); and its contributions from wind are restricted to interruptible loads (the identified potential for much bigger wind contributions to baseload requirements was discounted on grounds of excessive costs in the absence of suitable energy

storage).* This scenario became the Supply Panel's "National Commitment" scenario. That Panel then produced an intermediate, "Enhanced Supply" scenario by selecting only the more economical of the "High"/"National Commitment" scenario's technologies and deploying some of them less rapidly than in the higher scenario (Davis and Culler, 1979, p. 174).

By now the potential for confusion arising from CONAES' treatment of renewables should be quite apparent. Unfortunately, the final report of the study (written by the Steering Committee and Academy staff assigned to the study) did not diminish that potential, it succumbed to it and magnified it.

Part of the added confusion was engendered by yet another set of scenarios--the so-called Study Scenarios, produced mainly by CONAES staff and consultants as a synthesis of Demand-Panel and Supply-Panel scenarios around which the Steering Committee could build its discussion of alternative futures. The Study Scenarios showed "solar" contributions (renewables exclusive of hydro and geothermal) of 2 to 6 quads in 2010, with the higher figure identified as corresponding to the Supply Panel's "Enhanced Supply" conditions (Brooks et al., 1979, pp. 571-578). As indicated earlier, however, the actual "Enhanced Supply" scenario by the Supply Panel contains about 12 quads of "solar" in 2010. Cutting this figure in half to get the "solar" ceiling used in the Study Scenarios turns out to have been based on nothing more than the intuitive judgment of the staff members constructing the scenarios, concurred in by one or more Steering Committee members they consulted, that six quads seemed more reasonable than twelve.

That the Study Scenarios spanned a much narrower range of possible contributions from renewables than indicated in the underlying work by the Solar Resource Group and the Supply Panel is unfortunate. This situation not only was certain to mislead the study's audience, it evidently misled the Steering Committee itself! For if the small role of renewables in the Study Scenarios did not actually stimulate the pessimistic passages about solar potential that appear in the final report--and it may have done so (a member of the Steering Committee myself, I do not know for certain who wrote those passages)--it was at very least the impression created by the scenarios that produced Committee acquiescence to these statements. It must be remembered that the Steering Committee did not <u>have</u> the final report of the Supply Panel when it was writing and reviewing its own report. The report of the Solar Resource Group had been distributed, but, amidst the thousands of pages of drafts and documents the Steering Committee received, it probably was not read carefully, if at all, by many. I do not think, then, that most members had any idea where the 6-quad ceiling on "solar" in the Study Scenarios actually came from. Many probably thought that the composition of the supply side in the scenarios had emerged from or had been certified by the extensive computer modeling work conducted as part of the study. (With respect to the contributions of renewables in the

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* Had a CONAES "Technical Limit" scenario been formulated by summing the Solar Resource Group's maximum estimates for each technology it considered, the 2010 total would have approached 60 quads, exclusive of hydropower and geothermal. (Geothermal and hydro were the province of other groups.) Such a total is of course not very informative if it contains quantities of some energy forms (e.g., interruptible electricity) bigger than the markets for those forms.

Solar Group scenarios, the Supply Panel scenarios, and the Study Scenarios, the computer models actually played no significant role. The cost assumptions used in the models were such that "solar" sources invariably contributed only 0-2 percent of 2010 supply, unless stringent limits were placed on the use of coal, oil shale, and nuclear power, whereupon the "solar" contribution reached as much as 50 percent. See Koopmans, 1978, pp. 13-14, 58.)

The key statements about all this in the final report--those that attracted press attention and created the appearance of strong disagreement with other, roughly contemporary studies--were of two kinds: statements that market forces alone would bring about little use of solar, and statements that the economic cost of massive intervention in the market to accelerate solar use would be astronomical. In the first category, one finds (Brooks et al., 1979, p. 44):

> "However, with energy prices in the range considered by the CONAES study, market penetration by solar energy (apart from biomass and hydroelectric) would be only a few quads up to 2010."
>
> "Under present market conditions, solar heating systems are usually not competitive with other available technologies, and therefore market forces alone will bring about little use of solar energy by 2010--probably less than 6 quads even if average energy prices quadruple."

Why the first statement is formulated to exclude biomass, and why the second jumps from a contention about solar heating to a conclusion about all solar energy, are minor mysteries not worth dwelling on here. For what is more misleading in the statements is their contention that solar penetration was investigated and found to be small at the highest energy prices considered by CONAES. This contention is simply incorrect. The highest energy prices considered entailed a quadrupling between 1975 and 2010 of the average real cost of energy to consumers. (Demand Panel Scenarios A* and A and Study Scenarios I and II are based on this price trajectory. Brooks et al., 1979, pp. 7, 9, 537-543.) However, neither the Modeling Group nor anyone else investigated analytically the penetration of renewables under such circumstances. If the estimates of the Solar Resource Group about costs of renewables had been employed in such an analysis, my reading suggests that the 2010 penetration of renewables would have come out at about 20 quads, exclusive of hydropower and geothermal.

On the subject of the monetary costs of implementing a more rapid penetration of renewables than the marketplace would dictate, the key statement is (Brooks et al., 1979, p. 44):

> "Under these conditions, solar technologies might provide as much as 25-30 quads of total energy needs by 2010, but the total price (at today's costs) could be enormous, running to a cumulative total of several trillion dollars--2-3 times the cost of alternatives."

Elsewhere (p. 351) a specific figure of 3 trillion dollars is mentioned. This contention is both ambiguous (what is included in the costs is unclear) and undocumented anywhere in the CONAES reports (no calculations are shown of the

monetary costs of any of the solar scenarios*); but more importantly it is uninteresting. Is it any surprise that, if renewables never became cheaper than in 1975 and conventional energy sources never became more expensive, getting 25 quads from renewables would cost a great deal of extra money? What would be interesting is the extra cost of a high-solar scenario in the much more likely circumstance that the costs of renewables fall after 1975 and the costs of the alternatives rise. Absent calculations for a range of such possibilities, it would have been wiser to say nothing quantitative about the monetary costs of high-solar futures.

The report of the Domestic Policy Review of Solar Energy handled this issue (and a good many others) in a more sensible and more illuminating manner than did CONAES. The DPR report (Domestic Policy Review, 1979, Vol. 2, p. B-246-263) explains, carries out, and displays a detailed calculation of the extra consumer costs (compared to a future with no renewables beyond those in place in 1978) that would be incurred over the 1978-2000 time period in achieving its "Base Case", "Maximum Practical", and "Technical Limits" renewables contributions. These extra costs, which net out the savings from displacing conventional sources (assuming an oil price of $25/bbl), come to 60 billion 1978 $ to reach the "Base Case" 10 quads in 2000, $180 billion to reach the "Maximum Practical" 18.5 quads, and $320 billion to reach the "Technical Limits" 28.5 quads (hydro contributions and costs included). The penalties of course would be smaller if the renewables cost trajectory fell below that assumed by the DPR or if the oil price turned out to be higher. At the levels stated, the extra costs for the high-solar futures are in the range of 1-5 percent of the nation's total energy bill over the 22-year period.

If one sets aside the more misleading and unfounded elements in CONAES' treatment of renewables--the spurious 3-trillion dollar cost penalty for the "National Commitment" scenario, the "Business as Usual" scenario that is less favorable to renewables than business as usual already was in 1978, and the completely arbitrary renewables ceiling in the Study Scenarios--then what remains is perfectly compatible with the results of the Domestic Policy Review. That is, in assumptions and in estimated penetration by renewables, the "Enhanced Supply" scenario of the CONAES Supply Panel corresponds roughly to the "Base Case" in the DPR, and the CONAES "National Commitment" scenario is similar to the DPR's "Maximum Practical Effort" (see Table 2).

GROUP 3: MITRE and EIA

Both the MITRE and Energy Information Administration studies used computer models of considerable sophistication to estimate the penetration of renewables in the year 2000 and later. The MITRE analysis is regionally disaggregated; the EIA work treats a single, national energy market. (The EIA uses regionally disaggregated models for its mid-term forecasting, but not for the long-term

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* The 3-trillion-dollar figure turns out to have come from a "back-of-the-envelope" calculation by one of the study participants. Later, the "envelope" could not be produced. For details of the flap caused by the study's use of this unsupported contention, the reader should consult the editorial page of the New York Times for January 16, February 26, March 1, March 27, and April 9, 1980.

studies that produce the year-2000 and later estimates of interest here.)

In both studies, however, the crucial information as regards the penetration of renewables--the costs of renewables and conventional alternatives as functions of time--is supplied to the models, not computed by them. In the case of the EIA study, the assumptions supplied to the model about costs are generally unfavorable toward renewables. Various EIA scenarios consider oil prices up to $60 per barrel, but synfuels from coal (assumed cheaper than fuels from biomass) and electricity from coal and fission (assumed cheaper than wind, solar-electric, and OTEC) hold down the contributions of renewables even in the high-oil-price scenarios.

The MITRE model, too, computes penetration based on competition in the marketplace, but with two important differences. First, in MITRE's "Reference Case", the costs of renewables are assumed to fall rather rapidly, based on current RD&D programs meeting their cost goals. Effects of existing federal incentives for solar energy are calculated to represent an effective subsidy of $0.19 per million Btu (Bennington et al., 1979, p. 30)--which calculation permits such incentives to be accounted for in a market model--and this combined with the falling real cost trajectory for renewables produces about twice the quad contribution in 2000 projected by EIA (see Table 2). Second, MITRE considers the possibility that certain nonmarket benefits of the use of renewables (e.g., embargo protection, international stability, national security, increased employment, and decreased environmental hazards) may lead to additional subsidies being provided to encourage such use. Setting such subsidies at $0.90, $1.60, and $1.90 per million Btu leads, through MITRE's market-penetration model, to its "Accelerated" Levels I, II, and III estimates for renewables contribution in the year 2000 (14.7, 18.2 and 21.4 quads).

Specific Technologies

For further insights into similarities and differences in the recent studies of the potential of renewables, it is useful to disaggregate the estimated contributions by type of technology. Table 4 provides such disaggregation for a selection of the year-2000 estimates from the major recent studies. It is apparent from Table 4 that scenarios whose total contributions from renewables are similar often differ significantly in the way these totals break down by technologies. The following subsections treat some of these differences and their origins. Emphasis is given to three scenarios that are comparable in their total contributions from renewables and for which a reasonably detailed explanation is provided in the associated studies--CONAES' National Commitment, DPR's Maximum Practical Effort, and MITRE's Accelerated Level I. (Prices for the MITRE case are from Bennington et al., 1978.)

SPACE HEAT AND COOL, WATER HEAT

These low-temperature applications are the furthest along toward full commercialization of the "unconventional" renewables, and the assumptions of the CONAES, DPR, and MITRE scenarios concerning them are similar: all three show costs of active space heating declining from 6-7 1975 $ per million Btu of fossil fuel displaced in the 1980-85 time period to around 4 1975 $/$10^6$ Btu in the year 2000. Water heating is projected by all three to cost in the range of 2.50-3.50 1975 $/$10^6$ Btu in 2000, with passive space heating in the same range and active cooling somewhat more expensive. All three scenarios show year-2000 totals of

Table 4. Disaggregated Year 2000 Quad Contributions from Renewables in Order from Lowest to Highest Totals

	Space heat & cool, water heat	Industrial heat & small engines	Biomass including wastes	Elect. from STEC, PV	Wind	OTEC	Hydro
CONAES Business as Usual	0	0	0.1	0	0	0	5.0
EIA Low	0.5	0	4.5	0.4	0.1	0.03	3.3
CONAES Enhanced Supply	1.8	0.4	1.9	1.4	0.4	0	5.0
DPR Base Case (Low)	1.1	1.0	3.1	0.2	0.6	0	3.9
UCS Low	2	1	3	1	2	0	3
DPR Base Case (High)	1.6	1.4	4.4	0.4	0.9	0	4.0
MITRE Ref	2.0	2.2	3.5	1.3	1.7	0.1	4.0
CONAES Nat'l Commitment	2.5	1.6	5.4	2.2	1.4	0	5.0
DPR Max Pract. Effort	3.0	2.6	5.4	1.4	1.7	0.1	4.3
MITRE Acc I	2.6	2.6	4.6	2.2	2.5	0.2	4.1
CEQ Low	2	2	3	2	4	1	4
MITRE Acc III	3.7	4.2	6.3	3.3	3.5	0.4	4.6
UCS High	4	4	5	6	5	0	4
DPR Technical Limit	5.5	3.5	7.0	4.0	3.0	1.0	4.5

2.5-3.0 quads in this category, but, within this total, DPR shows much more passive heat (1 quad) than CONAES and MITRE (each at 0.3 quads). None of these three studies seems to have considered explicitly a potential contribution from neighborhood- or community-scale systems with seasonal storage, which might provide 100 percent of space conditioning and water heating needs for the homes serviced rather than the 50 to 70 percent generally assumed for individual-home solar systems. Assumed use of community-scale systems may account for the UCS "High" scenario's bigger contribution in this category.

INDUSTRIAL ENERGY

The diversity of industrial energy uses--ranging from low-temperature to high-temperature heat and process steam, as well as shaft work and electricity, in an enormous variety of applications--has impeded detailed analysis of this sector by students of the potential of renewables. By far the most extensive analysis among the studies considered here is that of the CONAES Solar Resource Group (Simmons, 1979, pp. 21-32), which estimated a total U.S. demand for industrial process heat and steam of 36 quads in the year 2000 (compared to 19 quads in 1975), with one fourth of this quantity, 9 quads, in industries whose processes are adaptable to solar supply and whose locations are suitably sunny. Of this potential, the Resource Group's "accelerated" scenario for solar process-heat implementation succeeds in supplying 1.6 quads/yr by 2000 at costs averaging 5 1975 $ per million Btu of fossil energy displaced. The DPR and MITRE studies give cost estimates falling from 7.50-11 1975 $/10^6 Btu around 1985 to 2.50-5.00 1975 $/10^6 Btu in 2000, but offer little explanation of how their year-2000 estimated contributions of 2.6-3.5 quads are derived. Both DPR and UCS cite an Intertechnology Cooperation (1977) estimate of a potential 7.5 quads of industrial process heat from solar energy in the year 2000; this figure may well represent the sort of potential embodied in the CONAES 9-quad figure, rather than an estimate of how much solar process heat technology actually could be deployed by 2000. Use of solar heat-engines for industrial shaft-work applications was not considered explicitly by CONAES, although CONAES solar-electricity estimates include a contribution from solar cogeneration technologies ("total energy systems") in commercial and industrial applications. Rapid penetration of such engines conceivably is implicit in the higher solar-industrial estimates offered by DPR, MITRE, and UCS.

BIOMASS, INCLUDING WASTES

Biomass already was contributing 1.8-1.9 quads/yr to U.S. energy supply in 1978-79, mostly in the form of steam- and electricity-generation from pulp and timber wastes and heat from wood-burning stoves (Domestic Policy Review, 1979; Bennington et al., 1979). The CONAES Solar Resource Group's detailed breakdown of biomass potential for the year 2000 comprised 2.1 quads of municipal waste for direct combustion (in utility or industrial boilers) at 2.10 1975 $/10^6 Btu, 3.5 quads of fuel gas (600 Btu/ft^3) from agricultural and forest residues at 2.00 1975 $/10^6 Btu, 1.9 quads from combustion of biomass from terrestrial energy farms at 0.30 1975 $/10^6 Btu, and 0.5 quads of fuel gas from marine-farm biomass. The "National Commitment" scenario used 5.4 of the 5.6 quads in the first two categories and counted nothing from the biomass farms. This last omission seems to have been due partly to anticipated competition for land and water by higher-value agricultural enterprises and partly to concerns over environmental impacts of biomass plantations. The DPR "Maximum Practical" scenario, whose biomass total is identical to that under CONAES' "National Commitment", emphasizes the importance of forest residues

in reaching beyond its "Base Case" of 3.1 quads, and it does not mention energy plantations. The DPR estimates that liquids from biomass will fall in cost from 8.70 to 4.60 1975 $/10^6 Btu between 1985 and 2000 and that gas from biomass will fall from 5.00 to 3.30 1975 $/10^6 Btu in the same period. These costs and those estimated by CONAES are sufficiently attractive compared to likely costs of conventional fuels in 2000 that the potential contribution from these biomass-waste sources would be supply limited rather than demand limited. MITRE estimates somewhat higher costs for high-quality synfuels from biomass plantations (12.40 1975 $/10^6 Btu for methanol from silviculture, 4.80 1975 $/10^6 Btu for high-BTU gas from silviculture); its "Accelerated I" scenario has 0.4 quads from these technologies, 0.2 of gas from animal wastes, 0.7 from wood stoves, 0.1 from utility electricity from biomass combustion, and 3.2 from industrial uses of biomass residues.

SOLAR-THERMAL-ELECTRIC PLANTS, PHOTOVOLTAICS

Solar-thermal-electricity conversion (STEC) in large plants tends to be capital intensive, particularly in relation to the load factors achievable without massive energy storage, and it is opposed by some because this approach has the same centralized character as do conventional electricity technologies. If capital costs are normalized to equivalent electrical kilowatts at 70 percent capacity factor, cost estimates of CONAES and MITRE for central-station STEC in the year 2000 are 1900 1975 $/kW and the DPR estimate is about 2600 1975 $/kW. Accordingly, the contributions estimated by CONAES and MITRE for this technology in 2000 (in the "Accelerated I" and "National Commitment" scenarios), at 1.6 and 1.7 quads, are considerably higher than the DPR's "Maximum Practical" figure of less than 0.4 quads. (The DPR figure includes an electricity contribution from dispersed solar-thermal "total energy" systems, CONAES allows a separate 0.5 quads for electricity produced in this way, and MITRE envisions no significant electricity contribution from such systems.)

With respect to photovoltaics, CONAES takes a more pessimistic view: the "National Commitment" scenario includes no contribution from photovoltaics, on the grounds this technology is likely to be more expensive even than other renewable-electric schemes. The Solar Resource Group's year-2000 "middle" cost estimate is 1200 1975 $ per rated kilowatt, or about $4900 per equivalent kilowatt at 70 percent capacity factor; the Resource Group suggests that 4 quads of thermal-electricity generation could be displaced by this technology in 2000 if society were willing to pay 117 1975 $/10^3 kWh for the electricity. Possible breakthroughs, not to be counted upon, could lead to 16 quads from photovoltaics by 2010 at an electricity cost of 42 1975 $/10^3 kWh (capital cost of 2200 1975 $ per equivalent kilowatt at 70 percent load factor). MITRE estimates photovoltaic capital costs of 1500-2800 1975 $ per equivalent kilowatt and year-2000 contributions of 0.3 quads in electric utilities and 0.3 quads in dispersed residential applications. The DPR "Maximum Practical" scenario gets 1.0 quads from dispersed and centralized photovoltaics combined and assumes 2900 1975 $ per equivalent kilowatt as the year-2000 cost. The American Physical Society study of photovoltaics (Ehrenreich et al., 1978), which considered only central-station applications to be significant by 2000, estimated that penetration was unlikely to exceed 0.5 quads (1 percent of projected electricity generation) in that year. The UCS study considered as much as 4 quads/yr from photovoltaics to be conceivable by 2000.

WIND

The wind figures shown in Table 4 for the CONAES, MITRE, and DPR scenarios under consideration here are associated with year-2000 cost estimates of 900, 1100, and 1700 1975 $ per equivalent kilowatt, respectively. That CONAES has the lowest penetration despite the lowest cost estimate may be explained by the CONAES assumption that wind is used only for interruptible loads. The CONAES Solar Group estimated that up to 3.6 additional quads could be made available in the year 2000 for other loads, at considerably higher costs (68 1975 $/10^3$ kWh versus 22 1975 $/10^3$ kWh on interruptible loads). The DPR and UCS studies both advance quantitative arguments to show that reaching 5 quads or even more from wind in the year 2000 would pose no insurmountable logistics problem, if the incentives existed.

OTEC

Ocean thermal energy conversion is arguably the most speculative of the renewables considered here as regards significant commercial application by 2000, and the estimated contributions as summarized in Table 4 are correspondingly modest. Cost estimates for the year 2000 were in the range 1200-2000 1975 $ per kilowatt at 70 percent capacity factor. CONAES offers an estimate of an additional $800/kW for underwater high-voltage DC transmission 200 miles to shore.

HYDROPOWER

Present-day fossil fuel displacement by hydrowpower in the U.S. is about 3 quads in an average rainfall year. The DPR "Maximum Practical" estimate entails expanding conventional (high-head) hydro to 3.5 quads and developing an additional 0.8 quads at low-head sites. The year-2000 cost of the low-head hydro is estimated by the DPR at 2300 1975 $ per equivalent kilowatt. The MITRE estimate is 3.9 quads from conventional hydro and 0.2 from low-head hydro; the former figure probably underestimates environmentalist oppostion to new high dams. In CONAES, hydropower was the responsibility not of the Solar Resource Group but of the Electricity Conversion and Transmission Group, from which no report is available. The Supply Panel Report does not explain how the estimate of 5 quads/yr in 2000 was derived.

Conclusion: The Choices We Face and Why it Matters

If the policies and programs in place in 1980 concerning renewable energy sources continue in force and are implemented diligently over the next two decades, and if the prices of nonrenewable energy supplies continue to rise during this period (by far the most likely state of affairs), then renewables other than hydropower and geothermal probably will be contributing 6 to 8 quads per year to national energy supply by the year 2000. (If the average cost of this energy were $5 per million Btu, such a contribution would represent $30 to 40 billion dollars per year; if it replaced imported oil at $10/10^6$ Btu--$60 per barrel--its value would be $60 to $80 billion per year.) If government research, subsidies, and incentives for renewables were withdrawn, of course, or if the prices of non-renewable energy supplies somehow were to fall significantly, the contribution of renewables other than hydropower and geothermal in the year 2000 could be much smaller, perhaps 3 to 4 quads. If a societal commitment were made immediately to expand the use of the renewables, on the other hand, the year-2000 contribution

almost certainly could be doubled from the "present programs" figure, reaching 12 to 16 quads and conceivably more. With 3 to 4 quads from hydro--the possible extra quad over today's figure coming mainly from addition of turbines to existing dams, mostly small ones--the renewables total in this "societal commitment" scenario would be 15 to 20 quads in the year 2000. Assuming aggressive energy-efficiency programs hold year-2000 energy demand to 80-100 quads--as must be assumed if the energy future is to be contemplated with anything but unrestrained alarm--such a renewables contribution would amount to 15 to 25 percent of total supply.

Table 5. Renewables Contributions in the Year 2000 (Quads)--A Personal View

	Reduced Incentives	Present Programs	Societal Commitment
Biomass	3	4	5
Space Conditioning & Water Heat	1	1.5	3
Industrial Heat	0	1	3
STEC/PV/OTEC	0	0.5	2
Wind	0	1	3
Hydropower	3	3.5	4

My own view of how these three scenarios--present programs, reduced incentives, and societal commitment--might be structured is shown in Table 5. I stress that these estimates--which reflect my personal judgments of the plausibility of the analyses and estimates in the studies reviewed in this paper--are no more than one person's educated guesses. (I would like to avoid the pitfall, into which the CONAES report and others have stumbled more than once, of lending undue credibility to assessments that are necessarily speculative and judgmental.) Particularly if the higher of my figures turn out in time to be too low, I shall be delighted to be proven wrong.

When such a range of possibilities is presented to any group of people diverse enough to include an economist, the question is sure to arise: Why is any societal choice--other than the choices made every day in the marketplace--needed or warranted to encourage the penetration of renewable energy sources? If renewables become economically attractive compared to other energy sources, the argument goes, the marketplace will call forth renewables aplenty; and if they are not economically attractive, we are better off without them.

Renewables enthusiasts can be divided into two groups according to their responses to this position. The first group essentially embraces the economist's view, contending that the only government interventions needed at this point are those aimed at permitting energy markets to function: removal of price controls and subsidies for nonrenewable energy supplies; providing consumers with the information about dispersed renewable energy sources they need to make economically rational decisions; preventing the acquisition of monopoly power in the renewables field by utilities, oil companies, or others; and so on. In a truly competitive market made possible by such measures, says this first group, renewables will rapidly expand their share of energy supply on their sheer economic merit. This has been the argument most strongly pushed by Lovins (1977, 1978) in his advocacy of an energy future based mainly on renewables.

The second group holds that any renewables contributions brought about by the operation of competitive markets will of course be welcome, but that such contributions are quite likely to be smaller and slower than the public interest

requires. In this view, in other words, there are social benefits to the use of renewables beyond those captured automatically in market transactions, justifying subsidies and other incentives and interventions to produce a greater penetration of renewables than would market forces alone. Clearly, the idea that "external" costs and benefits of energy supply can be large enough to justify major interventions in the market is not a new one. Presumably the historical perception that ample availability of inexpensive energy produces significant macroeconomic benefits (rapid economic growth, high employment, competitiveness in international markets), beyond those captured in market transactions, has been responsible for the substantial government incentives and subsidies to conventional energy supply (estimated in a Battelle study quoted in the MITRE report as about 200 billion 1976 $ between 1950 and 1977; see Bennington et al., 1979, p. A-5).

In my own view, the most serious energy-related threats to societal well-being today are no longer those associated with the macroeconomic consequences of industrial nations having too little energy (although most developing countries still suffer mightily from having too little); rather, the gravest threats are associated with the macroeconomic, sociopolitical, and environmental consequences of having too much energy of the wrong kinds. Too much imported oil has adverse macroeconomic consequences through balance of trade; shores up the world market price, with crippling effects on oil-importing developing countries; makes us vulnerable to devastating embargoes; distorts our foreign policy; and indeed increases the chance of nuclear war in pursuit of our "interests" in the world's oil-producing regions. Too much nuclear power entails increased risks of the spread of nuclear-weapons among nations and even into subnational groups, and it exposes large populations to indeterminate probabilities of large releases of radioactivity caused by mismanagement, miscalculation, or malevolence. Too much fossil fuel means flirtation with a CO_2-induced climate change potentially catastrophic for world food production; acidification of rainfall, soil, and surface water over ever-larger regions; overcommitment of water supplies in the arid West; and increased public and occupational exposures to a diverse array of toxic substances. Too much emphasis on centralized electricity technologies by the industrial nations, which do essentially all the world's R&D, means plummeting prospects for the poorest nations, where these technologies are hardly usable. (These arguments are elaborated in, e.g., Holdren, 1975; Holdren, 1977; Ehrlich, Ehrlich, and Holdren, 1977; Harte and Jassby, 1978; and Holdren, 1978.)

It is these and other external costs--not lack of nonrenewable energy resources nor lack of money to exploit them--that make an energy future without rapid penetration of renewables so unattractive. It is these external costs, in other words, and the prospect that those of renewables will be more tolerable (Holdren et al., 1980) that make me and many other renewables enthusiasts believe that society will be willing even to pay extra, compared to the monetary costs of the nonrenewables, to get the energy it needs from renewables instead. No energy future, of course, can be free of significant uncertainties, risks, and costs. The need for energy policy arises because so many of these issues are beyond the reach of the marketplace; and the need for public participation in policy choices arises because there is no strictly analytical calculus for choosing which array of uncertainties, risks, and costs to bear--the "apples and oranges" trade-offs involved make the choices inherently political. One must be wary, therefore, of analyses that seem to narrow the range of achievable futures on grounds of what seems economically attractive. Economics is only one of many relevant criteria. Within a rather wide range of technical possibilities, it remains true that the energy future will be what we choose it to be.

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SOLAR ENERGY CONVERSION
UTILITY INTEGRATION

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INTRODUCTION

The development, demonstration and commercial acceptance of any service, product or system requires a thorough understanding of the marketplace. Since central station electric power applications are key to many solar energy uses, it is not only appropriate but essential that we understand and incorporate, in the research and development process, the needs of the users -- the electric utilities. The thrust of this paper, then, is to examine the solar central power station from the perspective of the utility planner. The focus is on three leading candidates among the multitude of solar applications currently under development. They include solar-thermal, photovoltaic and wind energy conversion.

In essence, this paper is an abstract of work comprising a five year program of the Electric Power Research Institute (EPRI) to analyze the impact of solar central station applications on electric utility operations. The effort has encompassed EPRI sponsored contractor research as well as in-house analyses by the program staff.

By way of outline, the following sections will address three major aspects of this analysis:

- Analytical approach to power plant evaluation
- Methodology
- Results and Conclusions

ANALYTICAL APPROACH

In measuring the value of solar-thermal, photovoltaic and wind central power stations to utility systems, research under EPRI contracts has used accepted utility industry analytical tools modified and supplemented for the operation of solar plants. Such assessments can be made without becoming embroiled in solar power plant cost estimate exercises which, by the nature of the current level of technological development, are attended by enormous uncertainty. With establishment of a sound methodology such as this for determining plant value, confidence in cost-value ratios will grow in proportion to confidence in plant capital and operating cost estimates. And, as the applications pass through the research, development and demonstration processes, quality of cost estimation will naturally improve.

This utility-system analysis approach to determining solar power plant value is of significant benefit to the R&D process itself. Utility system operational requirements, particularly as they relate to reliability and lifetime, have a profound effect on solar power plant design and operation. Early identification of these requirements is, therefore, essential for evaluation throughout the development process as we move from conceptual design through proof of technical feasibility, demonstration, utility integration and commercial acceptance.

METHODOLOGY

In implementing the approach, those analytical tools already accepted by and accessible to the electric utilities have been integrated into the methodology. Figure 1 presents a generalized evaluation study task flow chart for assessing the value and impact of solar-thermal, photovoltaic and wind power plants. Established utility generation planning tools applicable to the study of solar generation relate to system reliability, production costing, and generation capacity expansion. Added to these are solar power plant performance models which incorporate weather and solar radiation data as well as operational descriptions for solar energy collection, conversion, storage and power conditioning. Also necessary was the extension of models to permit hourly simulations because of solar radiation and weather variabilities.

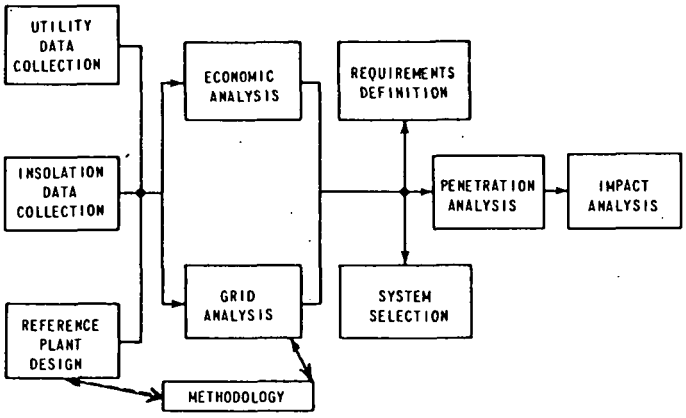


FIGURE 1 EVALUATION STUDY TASK FLOW

The initial tasks in assessing the value of the solar power plants, as indicated in Figure 1, relate to characterization of weather, plant reference systems and utility systems operation. To gain credibility and ensure a proper test, the methodologies had to be applied to actual utility systems. For this reason, very early in the evaluation studies, utilities were selected as part of the project teams. Weather and solar radiation data were subsequently collected for specific locations. In parallel with these activities, reference plant designs were defined and modeled to describe the various central and distributed receiver collection systems, storage options, and operational modes.

The principal economic measures of solar plants assessed through these methodologies are:

- Value of displaced energy
- Value of displaced capacity
- Solar plant busbar energy cost
- Net economic impact on utility
- Cost benefit of the solar plant

Reference plant cost models were developed to include direct cost for land, solar plant construction and balance of plant. Allowances for indirect costs such as contingencies, escalation to start of construction and interest costs during construction were also included, as were operating and maintenance costs.

Solar plant cost estimates, together with plant values, were used to derive cost/benefit ratios for numerous economic and operational scenarios integrating solar power plants as a function of solar plant capacity penetration. Subsequently, sensitivity analyses were conducted varying key economic and performance parameters.

In assessing alternative solar concepts, both cost and value were considered. Total system economic implications were compared with those of other designs in the context of actual electric utility systems. The procedure consisted of two distinct steps for each utility:

- Development of Future Electric Utility Generation System Scenario. A base case was defined for the year in which the solar plant would be added to the system. Defining this base case involved determining total system production cost and generation system reliability prior to installation of a solar plant. Each base case was utilized as reference for subsequent cases where solar plants were installed on the system.

- Comparison of Base Case With Solar Plant Addition, Using Single-Year Period.

  The value of the solar plant addition over the operating lifetime was established on the basis of a one-year simulation. Although more realistic results might have been obtained by performing probability and production cost runs for 20 or 30 years, such projection of system characteristics was considered too detailed for the present level of uncertainty in the performance and cost characteristics of the solar power plants themselves.

Conventional generating plants are subject to scheduled outages for routine inspections and service as well as forced outage resulting from equipment failure. A solar plant may suffer from further outages because of its dependence upon insolation characteristics, the amount of storage, and the plant's operating strategy. Conventional utility procedures for calculating generating system reliability (loss-of-load probability) were, therefore, extended to include the impact of these additional solar plant factors and to allow simulations on an hourly rather than daily basis.

As increasing amounts of solar plant capacity are added to a utility system, it is quite likely that the impacts of, and requirements upon, these plants will change. To assist in assessing the changes, two penetration procedures have been developed. The first procedure is one of time-static analysis. That is, a single year is used to form the basis of the implications of various levels of penetration. The results of detailed analysis and simulation of this single year are then used as a basis for estimating long-term impact. The second procedure involves time-dynamic solar penetration -- that is, penetration that increases over a period of years. The result of this analysis is a model which optimizes the expansion plan of a utility. This optimization is based upon minimizing the cost of energy to the customer while maintaining reliable service.

RESULTS AND CONCLUSIONS

In essence, the value of a solar power plant to a utility is determined by three elements:

- Capacity displacement credit
- Energy displacement credit
- O & M credits

In addition to the obvious dependence of solar plant operation on solar radiation characteristics, capacity and energy value strongly depend upon the utility systems to which they are applied. Along with fuel cost assumptions, the mix of conventional generating capacity by fuel type dominates solar plant value assessment.

Consider a scenario developed for Public Service of New Mexico, for example, as illustrated in Figure 2. Presented here are the elements making up the generating capacity by fuel type. Also shown are typical daily load curves for winter and summer days, describing a summer peaking utility. As one can see, operation of a solar power plant in the summer could be credited for the value of high-cost oil displaced with some intermediate or peaking capacity credit. On the other hand, in winter, the value of fuel and capacity displaced are for the less expensive coal-produced energy. A glance at the load-curve shapes also points out the importance of the full hour-by-hour simulation for a year for aggregating solar plant and total system operational costs.

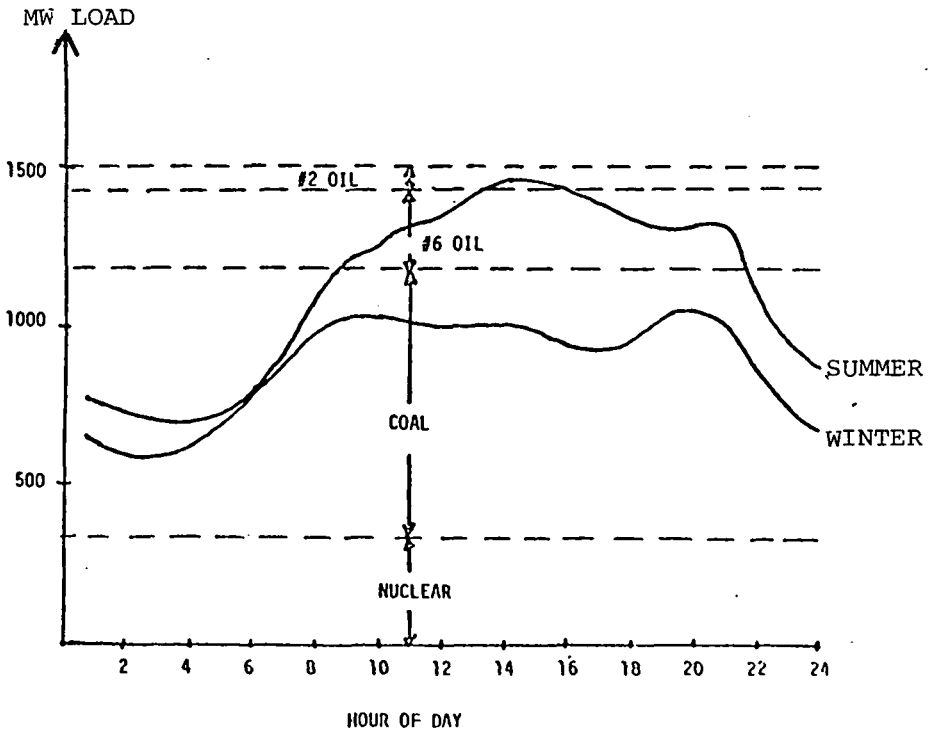


FIGURE 2 PSNM GENERATION MIX SCENARIO AND TYPICAL DAILY LOAD CURVES

Another common characteristic of the solar plant concepts studied relates to the incremental value of additional solar power plants as a function of penetration. As solar power plant penetration increases, incremental value decreases. Two factors are involved here. First, the energy displacement shifts to conventional units of lower energy cost. The second factor relates to plant reliability and availability. As previously mentioned, addition to the planned and forced outages to which conventional plants are subject, solar plants are also subject to outages due to the fickle nature of sunshine, wind and atmospheric conditions. Consequently, the incremental credit for capacity displacement decreases as more solar capacity is integrated into the system. In fact, the value of solar power plants diminishes substantially for utilities analyzed with penetration approaching 20 per cent of the annual peak load. Geographic dispersion of solar plants may enhance the value.

Aside from a buffer, which may be essential for stable solar plant operation, storage for purposes of load management may be considered either as dedicated to the solar power plant or integrated with the utility system as a whole. A consistent finding for all types of solar power plants is that storage should be considered for its value to the system as a whole. The inclusion of dedicated storage translates to an oversizing in solar energy collection equipment. In addition, operation from thermal storage is attended by diminished electric power generation efficiency. Electric energy storage, which might be used in photovoltaic power plants, necessitates oversizing of photovoltaic conversion arrays. From the utility system point of view, if inexpensive storage techniques were available, they could be integrated with utility systems quite independently of solar power plants, with consequent increased independence from current and planned peaking generation requirements.

CONCLUDING REMARKS

A major difficulty in dealing with solar energy is the often overlooked reality that the stages of technological development -- in fact, the separate technologies -- are as diverse within the solar field as they are between solar and other alternative energy resources. For example, proof of the technical viability and approach to commercial acceptance of solar hot water and space heating by no means reflects the state of development of solar cooling. By comparison, the latter is much further down the road ahead.

Another example with seemingly conflicting signals is photovoltaic conversion. Single-crystal silicon cells are accepted as reliable and cost-effective for powering space vehicles. But they are much too expensive for use in central electric power production on earth or in competition with utility markets in distributed application. Development of different photovoltaic materials and/or cell geometries has the highest probability for economic success in large-scale applications. This calls for very basic research and development. And while we can be reasonably confident of the prospects and potential, it would be foolish to flatly guarantee a scientific breakthrough.

Finally, to follow the R&D process from basic research through demonstration, evaluation and education requires time and patience. Furthermore, the processes of measurement, analysis and communication must be conducted serially and must be carefully paced. If solar applications are to be successfully integrated into our nation's energy supply mix, it is essential that the overall R&D process be protected from insistent pressures to go too fast too soon.

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POTENTIAL IMPACT OF RENEWABLE ENERGY ON OUR TOTAL ENERGY IN THE LAST TWENTY YEARS OF THE TWENTIETH CENTURY

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To determine where we are going and what we are going to do with our energy in the next century, we must first know where we are today in terms of price and supply of fossil fuels as well as the price and "supply" of alternative energy.

TABLE 1
Energy Price Assumptions (in 1975 $)

	1975 (actual)		2010 (A and A* Scenarios)	
Oil Prices	$/bbl	$/MMBtu	$/bbl	$/MMBtu
Distillate #2	16.37	2.81	78.58	13.49
Utilities residual	12.40	2.02	59.52	9.70
Gasoline (before taxes)	19.80	3.64	91.58	17.47
Utility Natural Gas Prices		$/MMBtu		$/MMBtu
Residential		1.70		19.63
Commercial		1.41		15.89
Industrial		0.99		11.38
Total		1.29		14.84
Utility Coal	$/ton	$/MMBtu	$/ton	$/MMBtu
	17.68	0.81	70.52	3.24
Electricity	¢/kwh	$/MMBtu	¢/kwh	$/MMBtu
Residential	3.11	9.11	10.37	30.37
Commercial	3.25	9.52	10.83	31.73
Industrial	1.83	5.36	6.10	17.87
Total	2.70	7.91	9.00	26.37

Anyone who reads a daily newspaper knows we import as much as we produce domestically and that we have the world's greatest coal reserves. Gas utility advertisements would have us believe they have an unlimited supply of "cheap, clean domestic fuel", while each year we find less new natural gas than we use.

Solar enthusiasts know that solar domestic hot water is "cost competitive" with electricity almost everywhere today and also with oil. With decontrol, it will fast be competitive with natural gas. Low Head Hydro is cost competitive with imported oil. Photovoltaic is cost competitive in remote site usage today as is wind. If solar is considered in its generic sense, we are already producing as much of our nation's energy needs as nuclear power is producing.

Energy shall never be viewed as "conventional" vs "solar, renewable". If we maximize all our known sources plus conservation, we will still experience distortions in supply through the year 2000. Proper action now can help to minimize the discomfort of these shortages.

While experts and governments disagree to the extent of future supplies, most will agree that between satellite and other technology, we know where and about how much fossil fuel is left on this planet. The Harvard Business School's "Energy Future" concludes the largest increase in supply will come from conservation (40%) and from solar (20%).

TABLE 2 - Solar Contribution in 2000

Energy Source	Oil Equiv. (mbd)
1. Solar Space and Hot-Water Heating (including Active and Passive)	3
2. Other On-Site Technologies	2
3. Wood and Forest Waste	3
4. Hydropower (Large Installations)	2
TOTAL	10

The technology for most of this is in existence. Our industry has an existing capacity to manufacture better than twice the current sales. To utilize it, the marketplace must be stimulated quickly through increased tax credits, parity with competing fuels through either equal subsidy or equal market forces (i.e., real decontrol).

New, concentrated, sustained, consistent research and development programs should be initiated to determine the best new technologies, and incentives should be granted to promote commercialization. Whenever economic comparisons are made, they should be made on the basis of new supply vs new supply and "equivalent subsidies".

Solar, while it will contribute to the existing system of central energy production distributed over controlled lines, will also open up new opportunities in non-distributed, user-owned, user-produced energy. Even if a zero growth equaling 76 quads is in existence in 1990, the solar and conservation replacement of fossil fuels will have created 2.9 million jobs.

The Arab embargo of 1973 was a warning of how precarious our energy picture was. Since that time, many farsighted authors, experts and elected officials have recognized the problem and proposed possible solutions. The Legislative Branch has even authorized and appropriated significant sums of tax dollars to help solve the problem. Yet, the Executive Branch, through its employees in the agencies (D.O.E., H.U.D., H.E.W., S.B.A., V.A., AGRI, etc.), has squandered most of our lead time through the last three administrations. Traditional sources of energy supply have lead times of from five to twelve years from inception to delivery. What few decisions have been made have been very slow in coming, sometimes arriving too late. They have been inconsistent, causing the solar industry to constantly start up, only to stop again.

We know the problem. We have potential ways to alleviate the problem, but unless the government either acts in a positive, consistent, speedy, solution-oriented mode or gets out of energy altogether (the opposite extreme of the pendulum), the potential of renewables will be diminished to an undistinguishable point. If this is allowed to happen through either deliberate action or lack of action, the net deficiency in our energy supply will be as irretrievable as the Twentieth Century.

ENERGY SELF-SUFFICIENCY FOR HAWAII

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I. The Hawaii Setting: Energy Use and Supply Pattern

Hawaii's written history began a couple of hundred years ago in a setting with a completely self-sufficient energy base -- a scattering of villages supported by comparatively simple agriculture, aquaculture, and ocean plant- and animal-gathering activities, with no electric lights or gadgets, no motor vehicles, airplanes, motor boats, heaters or refrigerators requiring energy for their manufacture, marketing, distribution and use as essential commodities. The arrival of Captain James Cook in 1778; the subsequent westernization influences; incorporated territorial status 80 years ago; and finally, full-fledged membership as a State of the Union only 21 years ago -- all these influences and political-status changes altered radically the energy use and supply pattern of the people of the Islands.

Today, the State of Hawaii has a resident population of close to one million, dispersed on seven of eight major islands. The Island of Oahu, with one-tenth of the land area, is occupied by 80 percent of the population. The land area of all the Islands totals 6,425 square miles; the eight major islands are strung over a distance of 350 miles and each Island is separated by some very deep waters in the middle of the North Pacific. Close to four million tourists arrive each year, averaging 10 days of visit each, and putting 100,000 additional daily energy consumers in Hawaii.

Today, Hawaii's standard of living compares favorably with that of other Americans throughout our great nation. It is not at all surprising, therefore, that both the pattern and the per-capita level of Hawaii's energy consumption generally resemble those of the nation as a whole. As in the other States, Hawaii's demand for energy arises from multifarious needs and uses: the production of food, clothing and shelter; the use of household appliances; commercial and industrial equipment, machinery and processes; labor-saving devices; temperature management; entertainment; transportation -- all these and more are needed and demanded by Hawaii's citizens no less than by citizens in other States.

Paralleling the similarity of demand is the way in which most of the energy demand has been met. As on the Mainland, Hawaii's energy has been supplied by large, centralized production units through similarly massive and technologically advanced distribution systems. This applies primarily to electricity, gas, and liquid fuels.

There is another parallel between Hawaii and the Mainland States. It is in the relatively free choice individual States made years ago to use petroleum as a major energy source, regardless of other energy forms accessible to each State in its own inventory of available resources. We have all used petroleum because of its superb convenience and, until recently, its low cost. We became "hooked" on petroleum and failed to develop other available resources.

While Hawaii's energy demand and supply patterns relate in general quite closely to those of its sister Mainland States, they do differ substantially in certain particulars:

- Hawaii's dependency on imported petroleum is nearly total. We are over 90 percent dependent on this energy source for our needs. The imported petroleum dependency figure for the nation is only 45 percent.

- Hawaii has no indigenous fossil fuels -- no coal, gas, oil, shale, nor off-shore oil.

- Hawaii's nearest neighboring State being 2,400 miles away across those deep ocean waters, no practicable way exists to tap into the interstate natural gas pipeline; to have railroad carriers fill bins with coal as their trains travel through the State; nor to arrange for Hawaii's electrical distribution system to tie into a regional grid system for moderation of peak loads and support during emergency down periods. In fact, due to the reality of our deep-ocean separation and the present economics of undersea cable technology, it is not even practicable to date to have electrical linkages between the eight major Islands of the State.

II. The Petroleum Crisis and Political Policy Responses

The 1973-74 oil crisis that shook the world needs no recitation here. However, it might be appropriate to suggest an opinion on how our nation and particularly the State of Hawaii faced up to that crisis, and have since pulled together certain policy responses of a strategic nature to cope with what has become a major problem of energy supply change resulting from the crisis.

While worrying about day-to-day fuel allocation in the 1973-74 period, fine minds in our State -- who much earlier had seen the handwriting on the wall and had promoted the idea of alternate energy resources -- carried out the extremely difficult process of explaining the basics and the complexities to public officials, legislators, the news media, and the general public. Public education and conservation came first, but it had to be joined to a short-, medium-, and long-term planning program designed to get us off petroleum as much and as soon as possible.

Paralleling our own rude awakening was the awakening of the rest of the Nation. But for many States, it was less of an anxiety. There was always nuclear power as the great ultimate salvation; there were possibilities for new dams and more coal and gas and U.S. petroleum offshore, and forests and shale; and adjacent States could help each other. But then a deeper anxiety set in; the Nation began to understand, as Hawaii had learned so much faster, that soon, the days of cheap and convenient oil would end, and in the long run there would be no more oil for energy production.

So most Americans looked to conservation for immediate relief; to coal, gas, and nuclear energy for the mid-term; and to what President Carter called "renewable and essentially inexhaustible energy resources" for the long-term future. Other countries followed the same pattern of concern and activity. Conservation became a household word. It would give the world some lead time before catastrophe arrived, or until we solved the problem through willpower, wisdom and technology. Innumerable problems and pressures arose. Citizens complained; government agencies and paperwork proliferated; nuclear power began to fade as an option as environmentalists worried; new energy businesses were formed; and the great campaign to

resolve the problem became political as well as technological, social and economic.

In thoughtfully considering all aspects of the problem, Hawaii faced basic policy decisions. Should we plan to go through the intermediate stage of imported-petroleum substitutes -- imported coal, imported gas, very high priced U.S. petroleum? Or should we head straight into the future and develop a number of renewable and essentially inexhaustible energy potentials we now discovered we had in abundance? There was very little doubt about the only answer. We began preparing for both the immediate and the distant future, as we paid the higher prices for our imported petroleum and intensified our earnest conservation efforts.

Events and actions came tumbling one upon another in and after 1974. The Hawaii State Legislature established the legal bases and provided the appropriate fundings for various energy programs, responsibilities and agencies, including the State Energy Resources Coordinator; the State Energy Office and State Center for Science Policy and Technology Assessment, all established in the Department of Planning and Economic Development; the Natural Energy Laboratory of Hawaii, a research and demonstration facility at Ke-ahole run by a managing board; the Hawaii Natural Energy Institute, a University of Hawaii research unit; and others.

We began a systematic examination of all potential alternate energy resources, no matter how "far out" they seemed. In February of 1975, for example, we published a 276-page volume, Alternate Energy Resources for Hawaii, a report of Governor George R. Ariyoshi's State Advisory Task Force on Energy Policy. The Task Force was established in early 1974. Its Committee on Alternate Energy Resources formed 14 task groups: on solid waste; bioconversion or biomass; hydroelectric; wind; geothermal; solar collectors; ocean thermal energy conversion; waves, tides, currents and osmosis; coal; nuclear; overview; economics; environment; and storage and transport.

Each task group did outstanding work in assessment of the problems and potentials, and in offering practical recommendations. The late Dr. Eugene M. Grabbe of our State Department of Planning and Economic Development, working closely with the University's Hawaii Natural Energy Institute and Dr. John W. Shupe, the Task Force Committee Chairman, must be credited with a large part of the guidance given to this auspicious pioneering assessment of Hawaii's alternate energy resources.

This year-long project set the stage and outlined the dimensions of the further planning work which was to follow. In our 1978 revision of the State Constitution, it was specifically mandated in Article XI, Section 8, that a two-thirds vote of each House of the Legislature would be required for construction of a nuclear fission power plant in the State, or for disposal of radioactive material in the State. So much for that potential! The 1974 State Energy Policies Plan was a first attempt to provide Statewide policies and goals in this complex field. It was followed by the 1978 comprehensive Hawaii State Plan, the first such State Plan enacted into law by any Legislature in the Nation. Among many things in this pioneering Hawaii State Plan, State objectives and policies for energy and utilities were delineated, and priority actions for energy use and development were listed. A State Energy Functional Plan -- one of 12 functional plans -- was mandated, and will be presented to the 1981 Legislature for final consideration.

It is difficult to sum up in a few pages the multitude of activities which followed the 1973-74 energy crisis. Federal programs and grants proliferated rapidly. Our State Legislature, increasingly concerned, took essential steps for matching newly available Federal funding and providing other State funding. University energy research expanded. Governor George R. Ariyoshi kept energy develop-

ment under the closest scrutiny, prodding sometimes lethargic agencies and enthusiastically supporting the more dynamic ones. Gradually things came into better focus. Hawaii began to see that it must develop energy self-sufficiency along a broad front of many different but complementary activities. Private industry, with much at stake, contributed in numerous benefical ways to the focusing and direction-finding.

During the years 1971 through 1979, alternate energy resources in Hawaii were authorized funding of a total of $61,838,000 with the Federal Government supplying $47.2 million; the State, $10.2 million; the Counties, $829,000; and private sources, $3.56 million. So the planning had brought forth the money authorizations for a great variety of planning, research, development, and commercialization projects and programs. And what was the focus of all of these? Renewable energy resources development, of course, plus continuing education and action for conservation, to help Hawaii achieve energy self-sufficiency.

III. Considerations and Operational Mechanisms for Carrying Out Energy Strategies

A sound strategy is, of course, essential to a sound solution of the long-term major energy problem of the State. Of equal importance are the nitty-gritties that help the strategies to be realized. There are many detailed considerations, assessments, evaluations and actions that need to be applied on a site-specific basis. These considerations and operational mechanisms must fit appropriately and adequately, and operate effectively, before the goal of energy self-sufficiency for Hawaii becomes a reality.

A consideration that requires ample allowance of time and effort is what might occur when a substantial shift takes place from the present system of energy production to that based on renewable energy resources. I noted earlier that we have centralized and relatively massive power generation facilities. Hawaii has centralized electrical generating power plants on each major Island; it has two petroleum refineries; and that's about it. The now developing multiplication of alternate energy resources -- geothermal, wind, ocean, solar, and so forth -- may well mean a fundamental social change for Hawaii. Put in simple terms, it could mean -- depending on the labels you wish to use -- a proliferation, a scattering, a spreading out, a dispersal, a multiplication, of energy sources, rather than a concentrating of such sources in massive central production stations. I point this out to encourage further thinking and discussion along these lines. It is such concepts which must be faced in our planning, and in our required discussion of the social impacts of energy policy-making, energy change, and alternate energy development. There are far-seeing philosophers who see in such straws-in-the-wind something very good for mankind. At the same time, competent economists -- who may also have a great empathy for the poor and the dehumanized worker -- call some of these concepts lacking in common sense, or see them as romantic little pies in the skies.

Good energy planning requires that we consider and debate all these things as we progress in a technology revolution. It is particularly important in Hawaii, where Hawaiian and other ethnic traditions differ from what might be simplistically labeled the Yankee traditions which are said to be the basis of America's industrial greatness. What needs to be melded here are Yankee concepts of getting a job done efficiently, with broader American concepts of democratic decision-making -- with the wishes of the people of a community, a district, an Island and a State clearly identified and willingly followed.

Another consideration that is critical to the carrying out of the strategy is the availability of human resources adequate to collectively seek, find, and

traverse the road leading to the goals defined by the energy strategy. There must be a "critical mass" of human talent. By "critical mass" I mean a pool of scientific, technical, managerial and related talent within a jurisdiction to undertake rather complex programs and projects. Some communities have the various talents and competencies needed to carry out their alternate energy resources dreams; others do not. Hawaii does have a basic pool of talent and the ability to selectively add to it to muster the sustaining teams capable of complex technological achievements.

Another area for broad discussion as we progress toward energy self-sufficiency involves the economic pace and pattern of progress toward our alternate energy resources objectives. This involves a host of economic considerations and the systematic development of cost/benefit data for a variety of energy scenarios, or energy development options.

We have nearing completion now a two-year project jointly funded and carried out by the Lawrence Berkeley Laboratory of the U.S. Department of Energy, and the State of Hawaii through our Department of Planning and Economic Development. It is the Hawaii Integrated Energy Assessment. It is a massive work, the purpose of which is to assist decision-makers, both private and public, with regard to the feasibility of, and the appropriate timing for, obtaining energy from renewable energy sources in Hawaii to replace that from imported petroleum. Basically, it is a tool for us to determine when the increasing cost of petroleum energy would cross with the anticipated decreasing costs of energy based on indigenous renewable energy resources. Private-sector involvement in both the process and the results obtained would encourage private risk-capital investment in a timely fashion. Knowledge of the relative impact on the overall State economy of the imported petroleum resource versus the indigenous resources would permit justification of certain incentives in favor of the indigenous resources. And awareness of the real cost of energy to consumers as well as of residual "production" costs to society in the form of environmental pollution from various forms of energy could provide further guidance to favoring one over the other. These are our expectations from the Hawaii Integrated Energy Assessment program. It is not fully operational now, but we expect it to operate well and keep us updated and to serve as a meaningful tool in clearing our way toward achieving energy self-sufficiency through use of renewable energy resources.

IV. A Systematic Implementation Mechanism: Hawaii State Energy Plan

The broad strategy for achieving energy self-sufficiency enunciated in the legislatively-enacted Hawaii State Plan (Act 100, Session Laws of Hawaii, 1978), is being carried out through a progressively detailed selection of specific objectives, policies, and implementation actions. The mechanism designed to achieve this is the Hawaii State Energy Plan, one of 12 functional plans required to be prepared by various functional area departments of the State under Act 100. The Hawaii State Energy Plan has been prepared under the direction of the director of the Department of Planning and Economic Development who is also the Energy Resources Coordinator for the State. Among the important processes and documents that feed into this Energy Plan is the Hawaii Integrated Energy Assessment. The Plan is reviewed by an advisory committee appointed by the Governor. It is then reviewed by the State Plan Policy Council comprised of principal department heads of the Executive Branch, planning directors of the County governments, and representatives of the general public. The State Energy Plan is brought out to the various island communities for information and public input. The Plan is then submitted with inputed advice and comments to the Legislature through the Governor. The enactment of the Plan by concurrent resolution of the Legislature serves as a basis for

allocation of available State resources for those projects listed as essential to carry out the earlier enunciated strategy for achieving energy self-sufficiency for Hawaii.

The State Energy Plan, in addition to serving as a basis for the State's resource allocations, also lends a degree of predictability of the actions of government, which should be helpful to private-sector investment in energy areas. We all know that with our system of government, the investment of private capital makes the greatest and the most sustainable impact. Through clear enunciation of public energy policies, through outlining in advance what specific public interests must be satisfied by those who invest in new energy production and distribution, and by declaring the degree of assistance public agencies are likely to provide in those ventures, the possibility of private-sector investment in those projects is enhanced.

V. Hawaii's Progress in the Implementation of Energy Self-Sufficiency Goals

Conservation

Hawaii has major energy conservation programs in operation now. Our State Energy Office estimates that Hawaii doubled its energy savings in 1979 over 1978 and trimmed its bill for imported oil by $50 million. Comparisons with other States based on Federal standards show Hawaii in 1978 was third highest in the nation in conservation results. And only seven States -- Hawaii included -- met or exceeded their 1980 energy savings goals ahead of time, in 1979. So Hawaii is doing very well in conservation.

Alternate Energy

Our geothermal activity is promising and exciting. We have drilled the world's hottest, and one of the cleanest, wells and will soon have electricity from this source in the Puna District of the Island of Hawaii. Hawaii in 1981 will be the second State in the Nation with on-line electricity from geothermal steam. This electricity will be fed into the Big Island's public utility grid. A private firm is now drilling for geothermal resources near the present well site entirely under its own financing arrangement. Related to the possibility of generating surplus electricity from this source, we are studying the use of deep undersea power cables for transmitting electricity from one Island to another.

The use of direct solar energy is proliferating in Hawaii. The most recent estimate is that our citizens have installed about 14,000 solar water-heating systems on residence rooftops and for commercial, industrial and institutional use. We probably have the Nation's highest per capita use of the sun to heat water. More than 60 companies are in solar water heating work in the Islands, providing systems, components, parts, services, and financing assistance for consumers anxious to convert from petroleum-based energy to solar. And on Kauai, a photovoltaic-cell installation is now in progress.

We come now to wind. Hawaii's famous trade winds blowing across our Islands form one of the most consistent and reliable wind patterns in the United States. The steady power of these winds is enhanced by Hawaii's terrain of mountains, cliffs, and plateaus. Favorable wind machine sites are found on nearly all of our major Islands and test wind machines are whirling now on Hawaii, Molokai, and Oahu. In July this year, a 170-foot-high wind machine began producing electricity for our Hawaiian Electric Company in Kahuku on Oahu. And the company has already signed contracts for what will be the world's first large-scale commercial wind

energy system, involving more than 25 wind machines in an 80-megawatt system which could provide, at capacity, electricity for more than 15,000 houses. The target date for completion is 1984. The wind machines, on well-designed pylons, will be about 350 feet high. Wind-machine technology is being tested throughout the Nation, of course, and refinements seem to improve the potentials month after month.

Hawaii does not view hydroelectric power as a major potential now, because of limited streams and land, although a number of small-scale hydroelectric power plants are presently operating and a few projects including a few run-of-the stream systems are envisioned. We are also considering the potentials for pumped-water power which in essence might use otherwise wasted power to put water into elevated tanks for peak-load assistance.

As most of you know, Hawaii has pioneered in ocean thermal energy conversion (OTEC). The world's first successful at-sea test of a closed-cycle system occurred August 2, 1979, on a borrowed Navy barge off Ke-ahole Point on the Island of Hawaii. It was highly successful, proving the concept works. Lockheed, the Dillingham Corporation and other private firms deserve commendation for their great contributions to OTEC's success. A second major program to test a much larger OTEC system is the OTEC-1 project, on a large ship and again, off the coast of Hawaii Island. Concurrent with this testing is the development of the State's Seacoast Test Facility at Ke-ahole Point, where on-land OTEC components and systems will be tested, along with ideas for aquaculture development using OTEC-related systems.

We are looking ahead and have published a new report, OTEC for Oahu, which sets the stage for construction of an at-sea OTEC plant close to an on-shore power distribution system. National OTEC legislation introduced by Hawaii's Senator Spark M. Matsunaga was approved by Congress and signed by President Carter July 17, 1980. It established a long-term national goal of 10,000 megawatts of electrical generating capacity, or energy-product equivalent, from OTEC systems by the year 1999. To achieve this goal, the Secretary of Energy is authorized to build and operate two OTEC demonstration facilities on a cost-sharing basis with private industry. It goes without saying that America's continued leadership in OTEC technology will insure opportunities for American companies to help strengthen the Nation's economy through export of OTEC-related technology and machinery throughout the world where such technology and machinery will be in increasing demand.

Another major alternative to petroleum for energy production in Hawaii is biomass. I modestly claim Hawaii to be the sunniest State in the Nation. One estimate is that the solar radiation reaching Hawaii is 26 percent higher than the national average. Measuring sunshine throughout all the States is difficult, so in reporting Hawaii to be the sunniest State I mentally included our aloha spirit to be on the safe side. Whatever the statistics, it is true that we have a vast amount of raw solar power reaching our Islands. It produces vast quantities of biomass, and these can be employed in various ways for energy. Hawaii has been using sugarcane waste -- bagasse -- for years, for generating electricity. Data for 1978 show that about 8 percent of all electricity produced in the State comes from non-fossil fuels, primarily bagasse. On the Big Island, the figure is 42 percent; on Kauai, it is 38 percent and soon to go much higher with new facilities for burning more bagasse; on Maui, 23 percent, and on Oahu, 2 percent. Bagasse is only one of numerous biomass potentials. Ethanol can be produced from molasses which comes from sugarcane processing, and from other growing things. A modest ethanol plant is being made operational now on Maui, and serious consideration is being given by sugar interests to converting their 300,000 annual tons of molasses

into ethanol for gasohol use. Tree farms produce wood which can be used as fuel in various product forms. We already have an experimental energy tree farm established on the Big Island. Various other biomass potentials are being studied or tested in Hawaii, and a number of contracts have been awarded for projects designed to find the best ways to use biomass.

Other alternate energy potentials are being investigated in Hawaii, ranging from the production of oils from plants and algae to gases from animal wastes, and to fuel cells, which convert chemical fuel directly into electricity. Hawaii's gas company, Gasco, is one of 22 companies participating in a field-test program which will involve two 40-kilowatt fuel cells to be shipped to the Islands. Our telephone company and others are testing electric vehicles -- the ones you plug in overnight to re-power.

We are earnestly committed to energy self-sufficiency. One of our most recent requests to the Federal Government is to help us give our Island of Molokai, where more than 6,000 people live, its electrical energy independence before the middle of this decade. We have submitted a carefully developed plan to use on that Island a variety of renewable energy resources -- wind, hydroelectric, biomass, direct solar -- to achieve this end. We are confident that we can do it.

VI. Conclusion

I wish to conclude my statement by observing that all of us here share the determination to free ourselves from being "hooked" on petroleum, which in the short run will play havoc with our economic stability, and in the long run simply will run out. For those States that have other fossil fuels in their resource inventory, I say more power to them for using those fuels, provided adequate consideration is given to national environmental concerns. Let there be a reminder, however, that even those resources will be gone in the long run.

So it is that all of us must turn, sooner or later, to renewable energy sources for a perpetually sustainable yield of energy. Hawaii, the southernmost and sunniest State in the United States, has a special role to play in the use of renewable energy resources for national energy self-sufficiency. After all, it certainly would be more prudent for the Federal Government to place its money where the probability of success is greatest.

We are grateful to the Federal Government for the support it has given Hawaii in our effort to achieve our own energy self-sufficiency. We are appreciative also of private-sector risk-capital involvement, which shares in our progress toward our self-sufficiency goal. With your continued assistance we hope to achieve our goal soon. And finally, we hope our pathfinder experiences will have meaningful transfer value to our neighboring Pacific States and territories as well as our sister-States on the Mainland.

RENEWABLE ENERGY RESOURCES FOR THE THIRD WORLD*

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I would like to introduce my remarks by seeking inspiration from a couplet of one of the beautiful poems of our national poet, Iqbal, which, translated into English, states:

> "Others may have a message (to give) but my message is different;
> I am a passionate lover and my style of expression (and of that love) is unique."

My love is for technology and my passion is energy, and my approach to them is a little different from that of others. My thesis is that the developing nations can provide significant help to the developed nations in matters of energy.

Although my background is nuclear, the opportunity that I have had at the United Nations to study energy problems on a global basis has convinced me of two things:

1) That nuclear energy is not the cheap and abundant source of energy which all of us thought, in the 1950s and 1960s, was just round the corner; and

2) That for reasons which I propose to discuss, selection by developed countries of sources and uses of energy cannot be adopted by the vast majority who live in the rural areas of developing countries.

I believe that today's search for alternative energy sources will be rewarded, just as we were rewarded in the past when we learned to use coal, oil, gas, and nuclear energy, which helped us first to sustain the tempo of the Industrial Revolution of the 19th century and then the exponential growth of the energy-intensive socioeconomic infrastructure of the 20th century.

Unfortunately, the geographical distribution of these sources is uneven. Coal is concentrated in the U.S., U.S.S.R., China, and Europe. There is little coal in Latin America or Africa (except in Columbia and South Africa). Oil and gas are also concentrated in certain locales; nearly 75% of the world's known deposits of oil are located in the OPEC countries, of which 50% are in the Middle East. Uranium deposits have not been fully explored, and some countries refuse to disclose information about them, but the major deposits in the non-Communist countries are located in Canada, U.S., Australia, South Africa, Niger, and Gabon.

The hydropower potential seems to be more equitably divided, although favorable sites are often far removed from centers of power consumption. These sites are also the source of political disputes which arise because construction of dams affects riparian rights of people in both the upper and lower reaches of the rivers.

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*This statement was assembled by the editor with permission of the author from recent publications Dr. Usmani has prepared. His oral presentation at the Conference will up-date this information and reflect his current viewpoint on this vital issue.

Let us review for a moment patterns of energy consumption. Total world consumption of energy prior to the so-called energy crisis of 1973 was about 2.5×10^{20} J/y, as against the total availability of about 2.4×10^{22} J. Thus, even if no new discoveries were made and world consumption remained constant, there appears to be little danger of a crisis in the next 100 years. But this simple arithmetic is, of course, dangerously faulty for many reasons. More than 93% of world energy consumption is accounted for by fossil fuels, 65% by oil and gas. Using this pattern to predict the future, however, will lead to serious distortion. Until 1973, oil was cheap, and because it can be shipped and stored easily, its consumption during the last three decades has risen sharply. This is alarming due to its thin resource base compared to that of coal.

Many people think that there are several areas where large deposits of oil exist which have not even been explored and that the oil crisis, therefore, is of a temporary nature. Unfortunately, this is a delusion. In the past, the rate of discovery of new deposits of oil has been, on the average, about equal to 1972 usage. But as promising areas similar to those in Alaska, North Sea, Mexico, Sudan, and China get scarcer and costlier to explore and exploit, and as the chances of finding new, huge deposits become more and more remote, it is unlikely that the past rate of discovery will continue. And consumption continues to rise.

A second distortion in world energy consumption is historical and geographical. Countries which pioneered and sustained the industrial revolution, and thus became technology-rich, consumed more energy than those which did not. In fact, if all available sources of energy are considered to comprise a "World Bank of Energy," it will be found that the industrialized countries, with only 30% of the world's population, have been drawing more than 80% of the bank's resources.

In 1971, the per capita consumption of power in the developing nations was 3700 kWh/y. In the developed countries (except the U.S.), the number was 33,000 kWh/y. In the U.S., it was 96,000. At the other extreme, some villages in rural areas show a figure of 300 kWh/y, but I know from personal experience in India, Pakistan, Bangladesh, Kenya, and Senegal that there are hundreds of villages where there is no consumption of conventional fuels at all. Life is sustained by locally available renewable energy sources: the sun, wind, water, and agricultural and animal wastes. When coal, oil, gas, hydro, or nuclear power are just not available in the villages of the Third World, the per capita energy consumption figures become farcical. As far as nearly on billion people in the remote villages of the Third World are concerned, the real fact is that they live virtually in an energy "vacuum."

Providing energy in the rural areas of developing countries poses one of the great challenges of our times. It will take a new conceptual and technological approach and new criteria of evaluation of projects based on the quantification of sociocultural benefits, which are generally ignored while making cost-benefit analysis purely in economic terms.

The Technology Crisis

Now with this overview of the global energy resource base and the rate and pattern of consumption of energy in mind, I would like to submit that the technologies employed for producing and using energy have a direct bearing on the energy distortions which prevail.

History, particularly of the last 100 years, has shown that *resource is a function of technology and technology in turn is a function of time and socioeconomic costs.* I am, therefore, convinced that if an energy resource, such as oil, is in danger of depletion, a well-supported R&D program launched in time could help. Here are examples of work already well underway:

- discovering new resources (oil shales, tar sands)
- finding substitutes (hydrogen or methanol)
- developing new processes (gasification of coal)

- improving the technology of recovery (secondary or tertiary deposits)
- improving the efficiency of using the resource threatened with depletion (improvement or replacement of the internal combustion engine).

In short, are we wasting threatened resources by using them where others could be used instead, and employing poor, inefficient technologies to produce and use them? To answer, let us examine the technologies involved. I think it would not be wrong to say that the whole modern industrial infrastructure is built around three basic technologies:

- electric power generation through the steam cycle
- the internal combustion engine
- the recovery of oil.

All are extemely inefficient. The thermodynamic efficiency of the steam cycle is 30-40%, so that whether we have a fossil-fuel-fired or a nuclear-fuel-fired power plant, some 60-70% of its heat content is wasted. The internal combusion engine is only 17-25% efficient.

I do not think very many people even begin to appreciate how costly and risky oil exploration can be. Deep on-shore drilling may cost as much as $5 million per hole and the chances against striking oil are on the order of 40 to 1! As accessible, geologically promising areas on-shore become fewer, more attention is given to exploration under the seabed. But the cost of such exploration is very high. To develop an oil field under the North Sea, it is estimated to cost $10,000 per daily barrel compared to an early '70s price of only $500 in the Middle East. But even when a successful oil field has been developed, the technology of recovery is so poor that only a third of the oil present can be pumped out. Thus some "abandoned" wells contain twice as much oil as taken from them. Efficient secondary and tertiary oil recovery could obviously alter the whole picture of this important source of energy.

No paper on problems and prospects of energy in the foreseeable future would be complete without an appraisal of nuclear technology, which has been with us for only a short time (less than 35 years) but has generated a lot of power and a lot of controversy. It is not generally realized that nuclear power reactors are very inefficient devices. *They utilize only about 1% of the fission energy of the fuel in the form of heat, and because this heat is converted into electric power through the Carnot-limited steam cycle, the end result is that we get less than 3/10 of 1% of fission energy in the form of electric power.*

These efficiencies are similar to those we encounter in solar energy conversion. Like nuclear, solar energy is a vast source of energy, and just as reactors can convert only 1% of nuclear energy into heat, trees also convert about 1% of incident solar energy through photosynthesis into wood. Again like nuclear heat, the heat from combustion of wood in a boiler can be converted into electric power through the steam cycle with the same 30% efficiency. Thus, if conversion of solar energy through combustion of biomass is considered to be inefficient, conversion of fission energy through reactors must be considered inefficient to the same degree. The only difference is that compared to wood, uranium is an extremely compact source, though far less ubiquitous.

Renewable Sources

It is unfortunate that in our race to develop compact, intensive sources of energy to sustain the infrastructure of the modern industrial societies of the 20th century, we have neglected to look into the potential that universally available, renewable sources offer. Admittedly, there are problems associated with developing these sources but, given adequate support, they can be harnessed to provide energy at the micro as well as the macro level.

The trouble is that during the last three decades world energy planners and decision makers made the mistake of placing all of our eggs in the nuclear basket, while in the interim relying on a supply of cheap oil. The events of October 1973 changed all that. Only then did we begin to look seriously to alternative sources of energy.

On a micro level, photovoltaic (PV) conversion of solar energy, production of biogas (50% methane) from agricultural and animal wastes, developing mechanical power from windmills, and tapping the river by installing mini turbines comprise technologies which already exist. But a push is needed to achieve competitiveness through mass production.

There is hardly any country which did not establish a national center to work exclusively on problems of nuclear energy on the model of Oak Ridge, Argonne, and Brookhaven. Why can't such national laboratories be set up for solar energy?

Developed Countries' Energy Strategy

The energy situation is manageable even though there will be painful adjustments in lifestyle and acute shortages for limited periods. Between now and the end of the 20th century, we can have breathing time to plan strategies suited to conditions prevailing in each region of the world. The developed countries are stuck, so to speak, with a centralized system of power distribution and an apparently insatiable demand for oil. If, therefore, any new source of energy or any new technology is to have a meaningful impact on their economics, it will have to somehow fit into the electric grid or substitute for oil in the transport sector.

Within this narrow "window" accessible to developed countries, there is bound to be a variation in strategies because of local availabilities. For example, the United States has fossil and nuclear fuels; western Europe has only coal and some oil in the North Sea, while Japan has practically nothing.

Something which all developed countries have in common is a broad scientific and technological base which they can mobilze to develop any field of their choosing. But in the context of the world energy situation, I think they owe it to themselves and the developing countries to undertake an intensive program aimed at renewable energy sources. If the poor countries take to the oil route, their demand would offer significant competition to developed countries.

Developing Countries' Energy Strategy

As far as the developing countries are concerned, they have two distinct sectors: urban and rural. About 90% of the population of Africa, 75% of Asia, and 55% of Latin America is rural, yet most development in these continents is confined to urban areas. Energy problems can thus be perceived as similar to those of developed countries except on a smaller scale. But in the rural areas, one sees that the situation is totally different. Nearly half the villages have fewer than 100 families and are located in remote areas. Such villages embrace over a billion people--a population equal to that of all the developed countries of the world combined--who subsist on primitive agricultural and live under eternal poverty. If any factor is responsible for this situation, it is the "energy vacuum." The muscle energy of men and their animals in a village has a limit.

Fortunately, the majority of these villages are in the world's "solar belt" (30°N and 30°S of the equator), which is ideal for implementing the micro techniques enumerated earlier.

Rural electrification via photovoltaics can meet energy needs for pumping water, irrigation, running small village industries, and powering electric lights to dispel that darkness which keeps the people illiterate and which, perhaps, even contributes to the population explosion. I envisage all electric power (and biogas) to be generated at what I call a "Rural Energy Center" (REC) outside the village with supplies

sent into individual homes. Thus, instead of training every family in the art of maintaining a particular device, we train only a few local young people. You will be pleased to know that under U.N. sponsorship three such centers are being established: one in Sri Lanka, one in Senegal (Africa), and one in Mexico.

Franklin Roosevelt, to combat depression, constituted in 1936 a special federal agency for rural electrification. It advanced soft loans at 2% interest to village cooperatives and utilities. Today not a single village in the United States is without electricity. In fact, in all the developed countries of the world, rural electrification has been accepted as an instrument of accelerating economic development and transforming life. I am convinced that no program of rural development is complete or meaningful without rural electrification. Unfortunately, economists of the developing countries, who are trained in Western schools, consider rural electrification to be uneconomic and therefore, give it low priority. They count everything in terms of economic return on investment. To them, a project which aims at removing illiteracy or improves health and happiness is nonproductive. They only chase the Lorelei of GNP without attempting to quantify social benefits.

In my country, Pakistan, results of planning by the Harvard- and the London-trained economists have been disastrous. After more than 30 years of independence, Pakistan has an external debt liability of about $7 billion. More than 80% of nearly 70 million people are totally illiterate. What is worse, the country, despite the fertility of the Indus Valley, has a chronic shortage of food grains even though it used to be the granary of undivided British India. In the field of energy, despite all favorable indications of the existence of oil and a large hydropower potential, Pakistan imports oil worth nearly $450 million per year, which amounts to about 40% of the total annual earnings of foreign exchange from exports. I recall an occasion when these economists, after working out the production cost of local wheat, found that it was more expensive than wheat imported from the U.S. and concluded that cultivation of wheat in Pakistan was uneconomic and should therefore be banned! I wonder whether they would commit suicide if free funerals were taking place! I think one of the great challenges before economists is to find ways to quantify social benefits.

Returning to rural electrification...I have worked out the figures in Tables 1, 2, and 3. They speak for themselves. Table 1 characterizes a typical village of a developing country in the solar belt; Table 2 estimates its energy needs; while Table 3 sizes the biogas plant and the PV panels required.

Because world production of PV cells is low, their cost is still excessive. There is general agreement, however, that with the buildup of demand and learning-curve improvement in technology, this price will come down exponentially. One way to break the price "barrier" is to build up demand by launching a vigorous demonstration program in about 300 villages in Asia, Africa, and Latin America and to offer industry a fixed price/fixed time contract of $3/W (peak) for installed systems.

Financing Rural Electrification for the Third World

It is my conviction that there is no dearth of money if only a concentrated internal effort could be mounted to wipe out the darkness from the villages of the Third World. Developing countries have money. Their military expenditure has gone up to more than $30 billion/y, and according to a World Bank study, they are planning to spend no less than $10 billion on rural electrification in the next 10 years. Further, bilateral and multilateral aid funds are available.

One possible method of financing rural electrification for developing countries is to collect a small tax (10¢/bbl) on oil imported by developed countries. Big oil-importing countries already tax oil to raise revenues for their own social welfare programs.

Table 1. A typical village in the "solar belt" of developing countries

Population	500 persons
No. of homes/huts	100
No. of cattle	150
Area cultivated (rain fed), one crop/y	200 ha
Depth of the water well	25 m
Average clear sunshine hours	2500 h/y
Annual average solar insolation	5 kWh/day
Conversion efficiency of solar photovoltaic (PV) cells in array	10%
Generation of electricity from a 1 kW peak panel* of solar PV cells	4 kWh(e)/day

*Each such panel is a kW_p (kilowatt panel)

Table 2. Village requirements

Drinking water, 20 L/person-day		10 m^3/day
Drinking water, 40 L/animal-day		6 m^3/day
	TOTAL	16 m^3/day
Irrigation water, 50 m^3/day-ha for 20 ha		100 m^3/day
Lighting for 100 homes having 3 fluorescent lights of 15 W each, all lighting for 5 h, 3 h, and 2 h respectively, per night		15 kWh/night
Street lighting with 20 fluorescent tubes of 25 W each for 10 h/night		5 kWh/night
	TOTAL	20 kWh/night
Max. battery storage required for 3 nights at a stretch with 50% discharge of batteries		120 kWh

Table 3. Standard requirements of energy (fuel and power) for a typical village (500 persons)

Fuel required for cooking (5500 Btu/person-day)		2.75×10^6 Btu/day
Electric power (kWh/day) required for:		
Pumping drinking water for humans and animals (see Table 2) from a depth of 25 m and storage in overhead tank 5-m high at 50% pumping efficiency	2.45	kWh/day
Pumping water for irrigating 20 ha for the whole year at 50 m^3/ha from a depth of 25 m at 50% pumping efficiency	136.00	
Lighting for streets and 100 homes (see Table 2)	20.00	
Village industries	30.00	
Commercial establishments and community centers	11.55	
TOTAL	200.00	kWh/day
Capacity of PV cells required to generate 200 kWh/day in the village	$\frac{200.00}{4.0}$ = 50.00 (peak)	

From what I have said, it is clear that the time has come to constitute an international organ under the auspices of the United Nations to keep the energy problems constantly under review and assist the developed and developing countries in planning their strategies and national energy policies along the lines indicated. Such an organization could serve as a data bank in the field of energy, help in the dissemination of information, undertake the demonstration and transfer of new technologies, award research contracts to solve short- and long-term problems, and assist in the establishment of centers of research and development on a regional basis, particularly in the developing countries.

As I say this, I am painfully aware of the limitations if such an organization were purely an intergovernmental setup. I believe as much in the dynamism of the private and public sectors in the energy field as in the importance of the contributions which members of academia can make to the solution of energy problems. I would therefore like to suggest that the proposed organization be a nonprofit-making International Energy Foundation with equal representation on its board of governors from the member-states of the U.N., the private and public sectors of the energy industry, and the members of academia belonging to centers of research and development in different regions of the world. The budget of this autonomous foundation should be financed out of the small tax on imported oil suggested earlier. By such international action alone can the crisis of technology be overcome, and by such action alone can energy independence, within the framework of interdependence, be translated into meaningful action without creating chaos and confusion. Thus alone can international cooperation replace a possible international confrontation on energy issues.

Finally, let me conclude by stating that the poor of the world face death by starvation, the rich by nuclear annihilation. The poor suffer from lack of technology while the rich have too much of it. The question is whether human wisdom can save them from converging to a common, tragic end.

SECTION 2

OVERVIEW PAPERS

OVERVIEW PAPERS

Tuesday, December 9, 8:30 A.M.
"Ocean Thermal Energy Conversion" 2-1
John R. Justus, Congressional Research Service

Tuesday, December 9, 11:00 A.M.
"Biomass Systems: A Strategic Overview" 2-19
Leslie S. Levine, U.S. Department of Energy

Tuesday, December 9, 1:30 P.M.
"Six Fallacies That Impede Planning for Regional Renewable Energy Systems" 2-21
Dennis L. Meadows, Dartmouth College Resource Policy Center

Tuesday, December 9, 4:00 P.M.
"An Overview Review of Dispersed and Central Wind Systems in the United States" 2-24
E. E. Johanson, JBF Scientific Corporation

Wednesday, December 10, 8:30 A.M.
"New Direction in the U. S. Solar Program" 2-38
Frederick H. Morse, U.S. Department of Energy

Wednesday, December 10, 11:00 A.M.
"Energy Storage and Renewable Systems" 2-49
George F. Pezdirtz, U.S. Department of Energy

Wednesday, December 10, 1:30 P.M.
"Comprehensive Overview Paper on Electric Energy Systems for Renewable Energy Technologies" 2-69
Kenneth W. Klein, U.S. Department of Energy, and *James A. Smith,* General Electric Company

Wednesday, December 10, 4:00 P.M.
"Overview of Geothermal Hydrothermal Development" 2-84
Bennie G. DiBona and Ronald S. H. Toms, U. S. Department of Energy

Thursday, December 11, 8:30 A.M.
"Photovoltaic Overview" 2-94
John V. Goldsmith, Solarex Corporation

Thursday, December 11, 11:00 A.M.
"Solar Thermal Energy Systems Program Overview" 2-102
Gerald Braun, U.S. Department of Energy

Thursday, December 11, 1:30 P.M.
"The National Hydropower Study" 2-110
Richard J. McDonald, Institute for Water Resources

OCEAN THERMAL ENERGY CONVERSION

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I. SURVEY OF THE CURRENT SITUATION

The ocean environment offers unique sources of energy, holding out promise for augmenting conventional energy sources and for reducing dependence on imported fuels. In this regard, interest has turned to an investigation of the renewable energy resource potential of the world ocean and the significance of the role it could play in adding a useful increment to U.S. energy requirements. Among the sources of renewable energy from the ocean are the temperature differences that exist between warm surface water and cold deep ocean water.

A. Description of the Technology

In 1881, French physicist Arsene D'Arsonval noted that a heat engine could be built to operate on the temperature differences between surface and deep ocean water. Credit also belongs to the American engineer Campbell who proposed the utilization of ocean thermal energy to produce power, employing a liquefied gas (e.g., ammonia, carbon dioxide, methyl chloride) as an intermediate working fluid. 1/

Thermal-to-electrical energy conversion in the ocean can be accomplished in two ways. First, sea water can be used as a "working fluid" in a method known as the "open cycle" whereby warm surface water is flash evaporated under a partial vacuum. The steam thus produced passes through and propels a turbine, and is later cooled in a condenser using cold sea water pumped up from the depths. The French engineer, Georges Claude, conducted experiments using this scheme in the early 1930s at a land-based test facility constructed on the coast of Matanzas Bay, Cuba, followed by an unsuccessful demonstration of a floating plant concept on board a converted cargo ship sited in deep water off the coast of Brazil. Variations of the open cycle, known as "lift cycles," are also being studied.

1/ See: Engineering News, August 7, 1913.

While Claude's open cycle process continues to receive study because of its inherent simplicity and avoidance of possible ecological problems resulting from use of other working fluids, a second method--known as the "closed conversion cycle"--is preferred by contemporary workers because it is believed to present the best solution on the basis of thermal performance, technical risk, availability of essentially off-the-shelf components, and the highest probability of early commercialization. Here, a secondary working fluid, such as ammonia, propane, or Freon-type refrigerant is vaporized and recondensed continuously in a closed loop to drive a turbine. Warm sea water is drawn from the ocean surface and pumped through heat exchangers wherein the secondary working fluid is vaporized; the working fluid then expands and emerges as a high pressure vapor to drive the turbine. From the turbine, exhaust vapor flows to a condenser where it returns to the liquid phase as it is cooled by cold sea water.

B. Known Resources and Reserves

The ocean thermal energy resource base is estimated to be of the order of 10^8-10^{10} (100 million to 10 billion) megawatts (Mw). Environmental consequences relating to a cooling of ocean surface waters could dictate an upper limit on ocean thermal energy conversion (OTEC) at about the 10^7 (10 million) Mw level, with the portion of that power theoretically extractable through an efficiency determined by the Carnot cycle of heat engines at about 10^5 (0.1 million) megawatts electric (Mwe). This represents an upper limit on the potential power capacity of this resource, and certainly only a small percentage of this calculated potential would ever actually be utilized. A detailed account of the range and limitation of the ocean thermal resource base is found in the Congressional Research Service study, ENERGY FROM THE OCEAN. 1/ Both coasts of Africa, the tropical west and southeastern coasts of the Americas, and many Caribbean and Pacific islands are situated where adjacent waters possess the year-round thermal characteristics required for operation of an OTEC power cycle. Potential areas of deployment for the United States include: Gulf Stream waters off the U.S. southeast coast, the Gulf of Mexico, Puerto Rico, the Virgin Islands, Hawaii, Guam, Micronesia, and American Samoa.

C. Current Contribution to U.S. Energy Supplies

At present there is no online OTEC generating capacity.

1/ Justus, John R. Ocean Thermal Energy Conversion. Appears in Energy from the Ocean. Report prepared by the Science Policy Research Division, Congressional Research Service, Library of Congress for the Subcommittee on Advanced Energy Technologies and Energy Conservation Research, Development and Demonstration of the Committee on Science and Technology, U.S. House of Representatives. 95th Congress, 2d session (committee print). April 1978. Washington, U.S. Govt. Print. Off., 1978. p. 25-28.

D. State-of-the-Art

Conversion, through an ocean thermal difference machine, of the ocean's thermal energy to electrical energy is not a new concept, but a full-scale ocean thermal power plant has yet to be built and operated successfully over a long period. Schemes for generating power from sea thermal gradients are, for the most part, based on extant technology and envision either partially submerged ocean-based platforms, high seas plant ships, or stationary nearshore platforms. Several proof-of-concept, baseline designs have emerged involving state-of-the-practice technology employing concepts, materials, and industrial processes currently known to industry. Still other plant concepts are predicated upon innovations in heat exchanger technology, hull design, and plant fabrication.

E. Current Research and Development

1. Domestic

A Federal OTEC development initiative began in 1972, under the auspices of the National Science Foundation's Research Applied to National Needs Program (NSF/RANN), as one of the six solar technologies constituting the original U.S. solar energy research and development effort. Those technologies were selected as being options that could each potentially provide a substantial contribution to the Nation's energy needs by the turn of the century. When the Energy Research and Development Administration (ERDA) was established on January 19, 1975, the lead role in solar energy was transferred from NSF to ERDA. This responsibility now resides with the Cabinet-level U.S. Department of Energy (DOE), established by Public Law 95-91 and officially activated October 1, 1977 (Executive Order 12009). The following table lists OTEC appropriations for FY72 through FY80.

TABLE 10. OTEC APPROPRIATIONS
[dollars in thousands]

FY72	FY73	FY74	FY75	FY76	FY77	FY78	FY79	FY80
$85	$230	$730	$2,955	$8,585	$13,500	$36,000	$38,200	$40,000

In fiscal year 1981, $39.0 million was requested by the DOE to continue the program.

Although OTEC program management is the prime responsibility of the Department of Energy, it involves other Federal agencies, as well as university and industrial contractors. Both the Department of Commerce and the U.S. Navy are participants. So are the DOE's Argonne, Lawrence Berkeley, and Oak Ridge Laboratories, as well as the DOE's Solar Energy Research Institute.

In the first phase of the development program, small-scale OTEC heat exchangers--up to 1 Mw thermal (approximately 25 kilowatts electric)--were designed and tested to gain an understanding of thermal performance and related biofouling (fouling caused by growth of marine organisms), cleaning, and corrosion of heat exchanger surfaces. In the second phase, now under way, a T-2 tanker was refitted for deployment in mid calendar year 1980 as a 1-Mwe test facility called OTEC-1. Five candidate heat exchanger designs and other large-scale systems components will be tested at sea and their performance evaluated. In the third phase a pilot plant is planned so that performance and reliability data can be obtained from a complete 10 to 40 Mwe system. Conceptual designs for such a plant have been considered in spar-buoy, ship, and land-based configurations. In addition to providing technical performance data, the pilot plant will allow a more accurate projection of costs for commercial OTEC power plants in the 100 to 400 Mwe range. The primary goal of the pilot plant program is the generation of electricity at a sufficient scale to convince potential users that large commercial OTEC power plants are feasible in U.S. mainland electric applications, or that smaller units (40 to 50 Mwe) represent a competitive alternative for the generation of base-load electricity for U.S. islands. 1/ 2/

2. Foreign

French scientists currently have a three-phase program coordinated by the Centre National pour l'Exploitation des Oceans, begun in 1978. The first phase, which ended in 1979, was a $1.8 million feasibility study for a 10-Mwe generating plant. The second phase runs through 1982 and calls for the selection of a specific working system and testing of major components. The suggested budget for this phase is about $5 million. The third phase involves construction of a demonstration plant in 1985 at a projected cost of up to $30 million.

Elsewhere in Europe, most interest centers on the efforts of EUROCEAN, a consortium of 25 industrial companies from 9 countries. 3/ In Brussels in February 1979, a EUROCEAN OTEC group was organized and included the following eight member companies: Alfa-Laval, Johnson Group, Kockums and Vattenbyggnadsbyram (Sweden); Banque Europeenne de Credit (Belgium); Hollandsche Beton Group (the Netherlands); Micoperi and Tecoromare (Italy). Funds for development of a 10 Mwe closed cycle plant were requested from the governments of Sweden, the Netherlands,

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1/ Cohen, Robert. Energy From Thermal Gradients. Oceanus, v. 22, no. 4, Winter 1979/80: 17.

2/ Rumbaugh, Jeffrey H., et. al. Thermal Energy Conversion: Tapping the Sea Depths. IEEE Spectrum, v. 16, August 1979: 42.

3/ Belgium, France, Great Britain, Italy, the Netherlands, Norway, Spain, Sweden, and Switzerland.

and Italy. Plans call for about $50 million to be spent over a five-year period. A related project calls for a combined aquaculture/OTEC/desalination plant.

Japanese development of OTEC began in 1970 with technical and economic evaluations of the concept. Since 1974, the emphasis has been on a 1.5 Mwe, land-based, experimental station. However, an ocean-sited demonstration plant with an output of 100 Mwe has been under development since 1975. In both cases the working fluid is ammonia, although other working fluids have been proposed. Considerable effort has been expended in their program on heat exchanger design and the identification of thermal and chemical pollution that might result from OTEC operations. The immediate future in Japan's OTEC development calls for the design and testing of a 1.5 Mwe, barge-mounted plant operating with ammonia across a temperature difference of 20 degrees C (36 degrees F). Commercialization is anticipated in the 1990 time frame. 1/ 2/ 3/

II. PROSPECTS OR REQUIREMENTS FOR FURTHER DEVELOPMENT

A. Research and Development

While proof-of-concept design studies have been completed using state-of-the-art technology, and although OTEC operating principles are well documented, both closed and open cycle systems do pose complex engineering and cost problems. Major analyses and studies conducted in the latter half of the 1970s have formed the basis for a large body of continually evolving research, analysis, and review of OTEC technology and its applications. The total available information and the complexity of the national OTEC research program have changed rapidly with quick progress from paper and laboratory studies to testing of hardware of significant sizes in both land and sea environments. Important test results have been obtained regarding thermal performance of OTEC heat exchangers and related biofouling, cleaning, and corrosion of heat exchanger surfaces. Principal investigators point out that refinement, optimization, and further engineering development are needed in several key areas in order to adapt the technology for economically competitive applications. Major studies are being conducted on power subsystems

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1/ Notes from Sixth OTEC Conference. Washington, D.C., June 19-22, 1979, and Seventh OTEC Conference, Wash., D.C., June 2-5, 1980.

2/ The French program is reviewed in the December 1978 issue of Solar/Ocean Energy Liaison newsletter, the Japanese program in the September 1978 and June 1979 issues, and the EUROCEAN porgram in the June 1979 issue.

3/ OTEC Projects Promise Electricity by 1990s. Chemical and Engineering News, Jul. 16, 1979: 25-26.

integration; platform/hull configuration; submarine electrical transmission cables; design, fabrication and deployment of the pipe required for cold water intake; long-term effectiveness of biofouling countermeasures in cleaning heat exchanger surfaces; alternatives to the ammonia vapor closed power cycle; and possible environmental effects of and on OTEC subsystems. 1/

B. Demonstration

Based on engineering development and advanced research and technology activities, major integrated power cycle systems are scheduled for testing on board OTEC-1, an ocean-going engineering test facility, and in OTEC modular experiments. Accumulated test data will be utilized in studies to project cost data for baseline designs of commercial OTEC systems to help determine optimum configurations for OTEC demonstration efforts. The modular experiments will provide for the building and operation of power plants about 10 Mwe in size during the mid 1980s. The results of these modular experiments will be made available to interested utility and industrial-user groups in order to aid the commercialization process. 2/

The first test of an ocean thermal energy conversion cycle began August 2, 1979, off Ke-Ahole Point, Hawaii. A closed ammonia power cycle was employed in Mini-OTEC, an experimental 50 kilowatt electric (kwe) gross power, barge-mounted ocean thermal power plant assembled from off-the-shelf components. The plant--not an optimized system--is testing key power system components under ocean conditions, while producing approximately 10 kwe of net power. About 40 kilowatts of the 50-kilowatt capacity went to run the plant's pumps and other operating equipment; the remainder powered test equipment onboard; no energy was transmitted to shore. Three million dollars in funding was shared by the State of Hawaii and a consortium of three corporations, and the plant was operated for the State of Hawaii by the Hawaii Natural Energy Institute, affiliated with the University of Hawaii. 3/ 4/ Currently, the DOE is lending support to permit Mini-OTEC to remain in operation and provide data to the OTEC program.

1/ Office of Solar, Geothermal, Electric, and Storage Systems. Ocean Systems Program Summary. Washington, U.S. Department of Energy, 1979. pp. 7-24. (DOE/ET-0083).

2/ Ibid., pp. 7-8.

3/ White, Hank. Mini-OTEC: She Runs. Ocean Industry, v. 14, no. 11, November 1979: 78-82.

4/ The three corporations are Lockheed Missiles and Space Company, Dillingham Corporation (a major Hawaii-based engineering and construction firm), and Alfa-Laval (a heat exchanger manufacturer).

An unsolicited proposal to construct and operate a 40-Mwe OTEC pilot plant ship was submitted to the DOE by a group of ammonia producers in conjunction with a number of agrochemical companies and a major U.S. shipyard. Plans for the construction of a high seas OTEC plant ship, which would produce onboard about 125 tons of ammonia per day, were summarized in testimony before the House Subcommittee on Oceanography and the Senate Subcommittee on Energy Research and Development. 1/ Details concerning submittal to DOE of an unsolicited Utility Site Support proposal for an OTEC demonstration facility also were outlined at these hearings. 2/

C. Commercialization

The stated objective of the U.S. OTEC development program is to demonstrate to industries and utilities the technical performance, reliability, and cost-effectiveness of OTEC systems in order to add a useful increment to U.S. energy supplies. The achievement of this goal requires both a favorable economic environment as well as the refinement of the technology. Many advocates believe that when the technology is made cost competitive, market forces will ensure that a substantial supply will develop naturally. Consequently, there is a preoccupation with cost comparisons--capital costs ($/kw) and unit energy costs (mills/kwh). Current appraisals

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1/ Under the leadership of Devco International, Inc. of Tulsa, Oklahoma, elements of the ammonia industry formed the Solar Ammonia Co., SOLARAMCO, to make the offer to DOE, in conjunction with Pullman Kellogg Co. and Avondale Shipyards. However, the DOE declined the offer.

2/ The proposal for construction and operation of a demonstration facility in partnership with DOE was submitted by Puerto Rico and contains a detailed plan for both Federal government and utility (Puerto Rico Water Resources Authority and OTEC Utility Users Council) participation. The government of Hawaii has also made an offer to DOE to share costs in the development of an OTEC pilot plant. Senate hearings were held Oct. 15, 1979; see U.S. Congress. Senate. Committee on Energy and Natural Resources. Subcommittee on Energy Research and Development. Ocean Thermal Energy Conversion Research, Development, and Demonstration Act. Hearing, 96th Congress, 1st Session, on S. 1830. Washington, U.S. Govt. Print. Off., 1980. 121 p. House hearings held Jun. 21, Sep. 20, 1979; Jan. 30, 31, and Feb. 27, 1980; see U.S. Congress. House. Committee on Merchant Marine and Fisheries. Subcommittee on Oceanography and Subcommittee on Merchant Marine. Ocean Thermal Energy Conversion. Hearings, 96th Congress, on OTEC oversight and on Ocean Thermal Energy Conversion Act of 1980--H.R. 6154. Washington, U.S. Govt. Print. Off., 1980. 495 p.

have tended to suggest that this is an oversimplification which disregards other economic variables such as lead time, domestic and international policy decisions, the availability of resources, and other realities of the market decision-making process. 1/ Until operational experience is obtained and economic performance can be verified through large-scale commercial demonstrations of OTEC technology, investment uncertainty will continue to exist. Assuming that the Federal Government does not intend to own and operate OTEC systems directly, the critical factor is whether the private and public sectors will raise the necessary capital and undertake the construction and operation of OTEC plants. In advance of economic competitiveness, a suitable economic environment might be created or artificially stimulated. If investment opportunity were not adequate, then a package of stimulating incentives might be considered, such as a combination of loan guarantees, low-interest loans, investment tax credits, and cost-sharing arrangements. 2/

Many factors are involved in OTEC commercialization beyond questions of technical and economic viability. Financing of OTEC plants must be obtained: it is yet to be determined who will be the owners or operators. Candidates include consortia of industries, utilities, and shipowners; leverage-lease financing is another possibility. Thus centralized OTEC facilities might be subject to decentralized control.

Operation of OTEC power plants and ships in the Economic Zones 3/ of coastal nations and in international waters may require bilateral and multilateral agreements among nations. Along with

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1/ Naef, Frederick E. Economic Aspects of Ocean Thermal Energy Conversion. In Proceedings of Joint Conference on Sharing the Sun, Solar Technology in the Seventies. K.E. Boer, editor. American Section, International Solar Energy Society and Solar Energy Society of Canada, Inc. Winnipeg, Aug. 15-20, 1976. Vol. 5, Solar Thermal and Ocean Thermal. Cape Canaveral, Florida, American Section of the International Solar Energy Society, 1976. pp. 393-411.

2/ Title II section 221 of the Crude Oil Windfall Profit Tax Act of 1980 (P.L. 96-223) provides a 15 percent nonrefundable business energy investment tax credit for equipment used to convert ocean thermal energy into electrical energy or another form of usable energy. The credit is allowed through Dec. 31, 1985, for qualifying equipment at two locations to be designated by the Secretary of the Treasury after consultation with the Secretary of Energy.

3/ The Economic Zone, or Exclusive Economic Zone (EEZ) as it is frequently called, is an area in which a coastal state has the exclusive right to explore and exploit the ocean resources lying off its coast between 12 and 200 nautical miles.

Government incentives, there may be a need to avoid regulatory features that might discourage financial investments. The relative attractiveness of OTEC as an investment opportunity, in an era when the demand for capital might exceed its supply, may be a strong factor in determining market penetration, perhaps outweighing questions of cost-competitiveness. Under the auspices of the Federal OTEC Program, investigations are proceeding on the legal, policy, technical, and financial incentives or proper combination thereof that may be required to create or artificially stimulate a suitable economic environment for investment in, and construction of, OTEC power plants. Studies have been initiated on technical integration of OTEC-derived electricity into electric energy networks by examining the planning and scheduling operations of electric utility systems. Until these issues are identified and settled, reliable estimates of the value of OTEC are difficult to make. In order to identify specifications for planning and scheduling operations of electric utility systems, present planning tools and philosophies of electric utilities will be tested against available OTEC baseline concepts. Analyses are underway of OTEC applications and market potential for OTEC products other than electricity. Although the electricity-to-shore-via-cable option appears to be the OTEC application nearest to being commercially competitive, it has been proposed that the power generated be used on-site for energy intensive refining and manufacturing processes on OTEC plant ships or at ocean energy industrial complexes (OEICs) when, at considerable distance from land, the transmission of electrical energy via underwater cable becomes prohibitively expensive. Provided the electricity is cheap enough to make a process economically feasible, the on-site production of chemicals, the synthesis of methanol, and the generation of hydrogen may have promising market potential. Also associated with ocean thermal systems are the possible options of producing food through mariculture, providing fresh water, and extracting ocean minerals. 1/

III. POTENTIAL OBSTACLES TO R&D OR TECHNOLOGY IMPLEMENTATION

A. Technical

Both closed and open-cycle OTEC systems hold promise for commercial applications. However, researchers in the United States regard the state of development of open-cycle technology as being less advanced (by several years) than closed-cycle technology. Because of the need in the open cycle to harness the energy in low-pressure steam, extremely large turbines must be utilized, and degasifiers must be employed to remove dissolved gases from the sea

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1/ Cohen, Robert. Energy From Ocean Thermal Gradients, pp. 17, 18, 21.

water. Recent open-cycle studies are encouraging, however, and point to cost-effective solutions to turbine and degasification problems. 1/

Closed-cycle power systems and their associated heat exchangers present several technical and cost challenges. The exchangers must transfer heat cost-effectively, and there must be a viable way to protect them against corrosion and biofouling layers, both of which inhibit heat transfer. Extensive at-sea testing near Hawaii and in the Gulf of Mexico has been underway for several years to establish biofouling rates and countermeasures. Chemical, mechanical, and sonic techniques can be used for cleaning the sea-water side of heat exchanger surfaces. The technical viability and cost of the heat exchangers are key factors, since they can represent up to half the total plant investment.

Other OTEC subsystems present technical problems that also must be solved at reasonable cost. In particular, viable solutions are being sought for designing and deploying OTEC cold water pipes and submarine cables. Candidate cold water pipe materials include fiberglass-reinforced plastic, elastomers, and lightweight concrete. Pipe lengths of about 1,000 meters will be required, with diameters of about 10 meters for a 40-Mwe power output. Submarine power cables rated at 100 Mwe or greater, including bottom and riser cables, will need to be designed to withstand unprecedented electrical and mechanical stresses.

Various platform configurations have been considered for commercial OTEC power plants, including ship, submersible, and land-based designs. Possible impacts of the environment on plant design and operation and, where submarine cables are employed, sea-floor conditions between the plant and the shore need to be taken into account. The ability to withstand severe weather conditions, for example, may necessitate the use of a submersible design. 2/ 3/

1/ See, generally, the papers in Session No. 9--Open-Cycle OTEC Power Systems and OTEC Cycle Innovations. Appearing in Ocean Thermal Energy for the '80s. Proceedings of the Sixth Ocean Thermal Energy Conversion Conference. Washington, D.C., June 19-22, 1979. Laurel, Applied Physics Laboratory/Johns Hopkins University and Washington, U.S. Department of Energy, 1980. v. 1; p. 9.1 -9.11. (Conf-790631).

2/ Ibid., pp. 15-17.

3/ Justus, John R. Ocean Thermal Energy Conversion. In Energy from the Ocean. Report Prepared by the Science Policy Research Division, Congressional Research Service for the Subcommittee on Advanced Energy Technologies and Energy Conservation Research, Development and Demonstration. Committee on Science and Technology, U.S. House of Representatives. 95th Congress, 2d session (committee print). April 1978. Washington, U.S. Govt. Print. Off., 1978. pp. 45-66.

B. Economic

Like most solar technologies, OTEC is capital-intensive, and the capital cost of commercial OTEC power plants may be a crucial factor in determining how competitive this source of energy will be in relation to other options. Based on available estimates, a reasonable target capital cost for the eighth OTEC production unit in the 100 to 400 Mwe size range is projected to be about $2,000 per kilowatt. However, costs may well exceed the target by up to 40 percent or may be lower by 20 percent. This estimate applies to the electricity-to-shore option, including the cost of a submarine cable system, for a plant located 140 nautical miles west of Tampa, Florida. Realistic estimates of capital costs vary from $1,500 to $3,400 per kilowatt of installed capacity. These capital costs lead to unsubsidized energy costs of 35 to better than 70 mills (3.5 cents to 7 cents) per kilowatt-hour of electricity if capacity factors, interest during construction, installation costs, and other financial assumptions are properly accounted for. Since OTEC plants do not require fuel for plant operation, a major cost component is for amortization of the capital investment. These estimated cost ranges are comparable to costs projected for other baseload power sources in the Gulf Coast electrical market for the years 1990 to 2000. 1/ 2/ Since the first OTEC power plants may be more expensive than later units, energy costs may be correspondingly higher initially. Even so, at island locations, such as Puerto Rico and Hawaii, where most of the electricity generated is derived from the combustion of oil, favorable electricity markets might exist for the first OTEC plants. The capital costs for OTEC plants at such locations could be less than those for plants off Gulf Coast States, both because the ocean thermal resource is somewhat better at these locations and the power cables would need to extend only several miles from shore. Accordingly, OTEC investigators have estimated that even the first OTEC commercial plants might be competitive in the 1990s versus an oil-fired alternative at island locations.

It is important to recognize that the foregoing estimates of OTEC economics remain speculative and uncertain because a commercial demonstration OTEC power plant has not as yet been built and because of the degree of as yet unpredictable escalation of OTEC plant cost estimates. However, based on the analyses and research performed to date, results of which were reported at the DOE-sponsored sixth

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1/ Cohen, Robert. Energy From Ocean Thermal Gradients, p. 17.

2/ Clorfeine, A.S. et al. DOE's In-house Assessment of OTEC: Summary of Principal Findings, OTEC Cost and Efficiency. The OTEC Liaison, v. 2, no. 11, November 1978: 1, 3-7.

and seventh national OTEC conferences, 1/ 2/ a consensus exists among the various OTEC investigators that engineering feasibility is assured and that a true economic break-even point may possibly occur in the early 1990s in island electric applications.

C. Environmental

Exploitation of the ocean's thermal energy involves the extraction of heat from the ocean through the circulation and redistribution of large quantities of warm ocean water from near the surface and cold ocean water from the deep. Local and widespread implementation of this technology might impact the oceanic environment and its surroundings by modifying the thermal, biological, physical, and chemical properties of that environment. Thermal perturbations might affect the optimum performance of the plant. For example, water exhausted from the evaporators or condensers, if recirculated through the warm water intake, could reduce the plant's net power output. Also, a reduction in ocean surface temperature might alter local climatic conditions, but appropriately directed discharge of the heat exchanger effluents could limit surface temperature decreases to a small fraction of a degree Celsius. Other possible consequences of OTEC power plant operation to be addressed include the impingement and entrainment of biota; possible discharges of biocides, corrosion products, and working fluids; artificial reef, nesting, and migration impacts; and worker safety. Research projects for investigating these concerns are summarized in a DOE environmental development plan for OTEC. 3/ Impacts of environmental parameters on the design, siting, and operation of OTEC plants are also to be considered and include the effects of winds, waves, and surface/subsurface currents on the power plant platform, and riser and bottom transmission cables. For instance, the quality of the thermal resource could be degraded by oceanic mixing associated with such natural phenomena such as coastal upwellings and hurricanes. Moreover, OTEC power plants must be designed to structurally withstand heavy seas. A knowledge base in this regard has been established by the offshore construction industry in the design and building of structures for operations in the harsh environment of the North Sea oil fields.

1/ Ocean Thermal Energy for the '80s. Proceedings of the Sixth OTEC Conference. Washington, D.C., June 19-22, 1979. Laurel, Applied Physics Laboratory/Johns Hopkins University and Washington, U.S. Department of Energy, 1980. 2 v. (various pagings) (Conf.-790631)

2/ Seventh Ocean Energy Conference. Expanded Abstracts. Washington, D.C., June 2-5, 1980. Arlington, Gibbs, & Cox, Inc. and Washington, U.S. Department of Energy, 1980. 1 v. (various pagings)

3/ U.S. Department of Energy. Office of Assistant Secretary for Energy Technology and Office of Assistant Secretary for Environment. Environmental Development Plan, Ocean Thermal Energy Conversion. Washington, U.S. Govt. Print. Off., 1979. 48 p. (DOE/EDP-0034).

D. Social

Secondary impacts associated with site selection, construction, and operations of an OTEC facility may also affect existing societal and institutional structures. New jobs would be created and shore-based "boomtown" growth might occur, with its associated impacts on housing, education, and sanitation. However, fabrication sites and techniques already are available in coastal shipbuilding communities. Protected deep water areas near deployment sites will be required for final assembly of modular plants, resulting in logistical transportation and support impacts typical for any deep-water construction project.

The use and/or production of chemicals or energy intensive products (e.g., ammonia as a working fluid, chlorine as a biocide, liquid hydrogen or ammonia as a product) and the possibility of collision with ocean going vessels could endanger the safety of operations and maintenance personnel. Worker safety concerns are regulated by the Occupational Safety and Health Administration and, for strictly marine occupational safety, by the U.S. Coast Guard. Worker-safety programs typically associated with construction and operation of large-scale projects might be implemented in accordance with the products or chemicals intended to be used or produced at the plant. Ocean traffic patterns might also be studied to determine the likelihood of collisions occurring at site designations. 1/

The construction and operation of OTEC vessels might provide social/economic benefits by generating new U.S. tax revenues, revitalizing the U.S. shipbuilding industry, and creating jobs in core city areas where many large U.S. shipyards are located. The current world shipping recession has reduced merchant ship construction opportunities, and the U.S. shipbuilding industry faces a crisis situation. 2/ The backlog of merchant shipbuilding contracts placed earlier in the 1970s is rapidly diminishing. Of 69 merchant vessels now on order in U.S. shipyards, only 22 will remain for delivery after 1980. Consequently, the shipyard resources of the United States may not be fully utilized. In all, more than 60,000 workers in U.S. shipyards currently face the prospect of unemployment, much of which will apply to minority workers in areas of chronic unemployment. With a multiplier effect factored in, nearly 200,000 workers in equally important supporting industries

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1/ Ibid., pp. 4, 24, 25.

2/ Statement of Edwin M. Hood, President, Shipbuilders Council of America. Appears in: U.S. Congress. Senate. Committee on Energy and Natural Resources. Subcommittee on Energy Research and Development. Ocean Thermal Energy Conversion Research, Development, and Demonstration Act. Hearing, 96th Congress, 1st Session, on S. 1830. Oct. 15, 1979. Washington, U.S. Govt. Print. Off., 1980. p. 104-105.

could be affected. 1/ Attendantly, in an analysis prepared for the U.S. Maritime Administration of effects in economic areas other than the power market, the Johns Hopkins/Applied Physics Laboratory estimated that the deployment of 21 commercial-size (300 to 500 Mwe) OTEC ammonia plant ships 2/ could create 100,000 new jobs in U.S. shipyards and additional jobs in the aluminum industry, in concrete, in steel, and in the industrial equipment sector of the economy. 3/ OTEC construction programs could be supported by such shipyards as those at Qunicy, Massachusetts; Norfolk, Virginia; New Orleans, Louisiana; and indeed by at least half a dozen large shipyards around the United States. Furthermore, new jobs would be created in the U.S. flag shipping industry through requirements to crew OTEC plants at sea. 4/

E. Political

The development of technology for ocean thermal energy conversion, is proceeding at a time when the law governing use of the world ocean is in flux, and issues of ocean rights and responsibilities may arise beyond those treated by conventional maritime law and treaties. It is possible that OTEC development may open up a new area of international interest in the ownership and operation of ocean-based energy-producing facilities.

The status of a cable-connected OTEC plant operating on the territorial or high seas warrants clear definition. Some experts define it as a moored ship, but others maintain that the permanent connection to to shore makes it an artificial island. This ambiguity in turn raises questions relating to technical design, insurance, royalties, and other economically oriented issues. This becomes less of a problem with untethered OTEC plant ships which are clearly vessels because

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1/ Ibid.

2/ Ammonia is a vital commodity in the manufacture of fertilizers, and over 95 percent of U.S. ammonia production uses natural gas in the production of ammonia.

3/ Avery, W. H. et al. Maritime and Construction Aspects of Ocean Thermal Energy Conversion Plant Ships. Laurel, Maryland, Johns Hopkins University/Applied Physics Laboratory, 1976. v. 1A, p. 4, and v. 1B, p. 1-8 and 1-9.

4/ Statement of E. J. Francis, Applied Physics Laboratory, Johns Hopkins University. Appears in: U.S. Congress. House. Committee on Merchant Marine and Fisheries. Subcommittee on Oceanography and Subcommittee on Merchant Marine. Ocean Thermal Energy Conversion Act of 1980. Hearings, 96th Congress, 2d Session, on H.R. 6154. Jan. 30, 31; Feb. 27, 1980. Washington, U.S. Govt. Print. Off., 1980. p. 310.

they can maneuver and/or drift. Siting an OTEC plant within the territorial waters of one nation may not necessarily avoid international legal problems if possible downstream impacts of OTEC operations are experienced.

Another fundamental legal question requiring resolution is the applicability of Federal and State regulatory law regarding the construction and operation of OTEC power plants. These Federal/State issues include exclusive or joint licensure authority; predominant roles regarding regulation of the OTEC facility; Federal agency jurisdiction (lead agency); and State jurisdiction (project review, assessment of on-shore impacts of constructing, operating, servicing, and receiving power and potential products from OTEC plants). These same investigations may be extended to encompass the problem of what international regulatory authority concerning OTEC plants exists now, or is likely to be developed or modified in the context of on-going United Nations Law of the Sea negotiations. A recurring question is whether OTEC would best be assimilated for purposes of legal responsibility and liability into the body of maritime admiralty law or whether some format for extending "land law" would be a better solution or, perhaps, some new combination thereof. 1/ Multilateral agreements or treaties among concerned parties (as is done for fishing rights) and domestic legislation may be necessary to resolve these potential legal problems. 2/

Legislation (H.R.6154 and S.2492) was introduced in the 96th Congress in an effort to resolve some of these legal problems. The bills provide for one-stop Federal licensing of OTEC facilities and plantships by the National Oceanic and Atmospheric Administration. Further, by treating facilities and plantships as vessels, they allow owners of OTEC facilities to use the capital construction tax treatment now available to vessel owners under the Merchant Marine Act of 1936 and extend to commercial and demonstration OTEC facilities eligibility for Federal loan guarantees under Title XI of the Merchant Marine Act

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1/ Legal, Political, and Institutional Aspects of Ocean Thermal Energy Conversion. Workshop Proceedings. Washington, D.C. Jan. 15-16, 1976. Washington, American Society of International Law, 1977. v. 1 (loose-leaf).

2/ Nordquist, Myron H. and Geoffrey S. Yarema. Generating Energy on the High Seas: Laws Needed to Protect Development of Sea Power. The National Law Journal, Nov. 26, 1979.

of 1936. 1/ The House and Senate have also passed H.R. 7474, calling for the demonstration of OTEC electrical or energy product equivalent capacity of 100 Mwe by the year 1986, 500 Mwe by the year 1989, and 10,000 Mwe by 1999. The bill directs the Department of Energy to prepare a comprehensive program plan and a commercialization plan that would permit realization of these goals. An OTEC Advisory Committee is established to assess and evaluate implementation of the programs mandated by the bill. 2/

IV. POTENTIAL CONTRIBUTION TO FUTURE U.S. ENERGY SUPPLIES

A. Contribution by 1990

It is not anticipated that OTEC will make any significant contribution to U.S. energy supplies by 1990.

B. Contribution by 2000 or Beyond

Initial projections of estimated OTEC power market penetration appear now to have been somewhat optimistic. For example, the 1974 Federal Energy Administration report, Project Independence, called for the achievement by the year 2000 of 165,000 Mwe, under a "business-as-usual" scenario, or 260,000 Mwe under an "accelerated" scenario. Under the accelerated scenario, OTEC technology was projected to save up to 7×10^{15} British thermal units (Btu) of fossil fuel energy per year or 11 million equivalent barrels per day of imported oil by the year 2000. The corresponding values for the business-as-usual scenario in the year 2000 were 1.7×10^{15} Btu and 2.7 million equivalent barrels per day of oil that would not

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1/ Hearings were held on Jan. 30, 31, and Feb. 27, 1980 by the House Merchant Marine and Fisheries Subcommittees on Merchant Marine and on Oceanography, and on May 1, 1980 by the Senate Committee on Commerce, Science, and Transportation. See also H. Rept. 96-994 on H.R. 6154 and S. Rept. 96-721 on S. 2492. Senate passed S. 2492 on July 2, 1980. House passed the measure July 21, clearing it for the president. President Carter signed S. 2492 on August 3, 1980, Public Law 96-320.

2/ Hearings were held by the Senate Committee on Energy and Natural Resources (on S. 1830) on Oct. 15, 1979; reported to Senate Dec. 14, 1979, S. Rept. 96-501; passed Senate Jan. 25, 1980; reported to House June. 13, 1980, H. Rept. 96-1092; passed House Jun. 17, 1980; passed Senate Jun. 28, 1980. Final action in the House Jul. 2, 1980; final action in the Senate July 2, 1980. President Carter signed H.R. 7474 on July 17, 1980, Public Law 96-310.

need to be imported from foreign sources. 1/ In these projections of reduced imports of fuel oil, it is assumed that the particular energy technology (in this case, OTEC) reduces the demand for fossil fuels to produce electricity.

In the 1976 report, A National Plan For Energy Research, Development and Demonstration, ERDA projected a total potential power capacity in the year 2000 ranging from 10,000 to 25,000 Mwe. This corresponds to a savings of 0.5 to 1.2 million equivalent barrels per day of oil used in the generation of electricity. 2/

It would seem very optimistic to expect that the technology could achieve the upper bound level of 260,000 Mwe in the year 2000. Even the figure of 10,000 Mwe may be optimistic for that time period in view of the fact that vigorous development plans would have to be undertaken promptly to achieve that capacity. A mix of alternate energy technologies will probably be implemented, which could result in a minute, but perhaps useful, incremental contribution from OTEC to the Nation's power supply approaching 1 percent by the year 2000. 3/

According to a recent assessment of OTEC market potential, the DOE observed that entry of OTEC into a U.S. mainland market is unlikely unless or until modular plant concepts and alternate platform designs have been successfully demonstrated, but in any case not before the year 2000. 4/ If proved a viable option, OTEC could potentially meet significant percentages of baseload electrical demands in the

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1/ Interagency Task Force on Solar Energy. Project Independence Blueprint. Final Task Force Report. Prepared Under Direction of National Science Foundation. Washington, Federal Energy Administration, November, 1974. p. I-7, I-9, I-25, VI-3.

2/ U.S. Energy Research and Development Administration. A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future. Washington, U.S. Govt. Print. Off., 1976. p. 108-111. (ERDA 76-1)

3/ Richards, W. E. The U.S. Ocean Energy Systems Program. Appears in Ocean Thermal Energy for the '80s. Proceedings of the Sixth Ocean Thermal Energy Conversion Conference. Washington, D.C., June 19-22, 1979. Laurel, Applied Physics Laboratory/Johns Hopkins University and Washington, U.S. Department of Energy, 1980. v. 1., p. 2.4-1 - 2.4-7.

4/ Clorfeine, A. S. et al. DOE's In-House Assessment of OTEC: Summary of Principal Findings, OTEC Cost and Efficiency. The OTEC Liaison, v. 2, no. 11, Nov. 1978: 1, 5.

U.S. Southeast and Gulf Coast region, possibly by the latter half of the 21st century. By 2020, a 20,000-to-40,000 Mwe OTEC installed capacity--a small fraction of the required baseload capacity for the Southeast--seems plausible, according to DOE projections. It seems likely, however, that initial commercial implementation for OTEC technology will be in tropical island electric applications of 10 to 100 Mwe replacement capacity. Puerto Rico, U.S. Virgin Islands, Hawaii, and Guam have expressed strong interest in OTEC, and economic, social and political factors appear favorable for the development of island markets at these locations. They have good ocean thermal resources, and the oil-dependent island utilities located there would be competitive makets for early OTEC plants. Conceivably, OTEC could deliver power to U.S. islands in the 1990s, if technical and economic feasibility were proven by the mid 1980s. Based on this assumption, DOE projects a total installed island capacity of 3,000 Mwe by 2000 and 8,500 Mwe by 2020. 1/ 2/

1/ Ibid., pp. 1, 5.

2/ Cohen, Robert and Fred S. Dunning, Jr. An Island Strategy for OTEC Commercialization. Preprint of an invited paper for Solar Energy and Conservation Symposium-Workshop. Miami, Florida, December 11-13,

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SIX FALLACIES THAT IMPEDE PLANNING FOR REGIONAL RENEWABLE ENERGY SYSTEMS

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Recent history gives solar energy enthusiasts many reasons for euphoria about the next two decades. Response to opportunities for increased use of solar energy has been substantial since the oil embargo of 1973. At one extreme has been growth in support for large, systematic studies of solar's potential, such as the project on "Distributed Energy Systems in California's Future" or the recent "Sawhill" report prepared by the Solar Energy Research Institute. At the other extreme are the hundreds of thousands of individual homeowners who have moved without fanfare to substitute wood for fossil fuels. In large parts of New England over thirty percent of all households, rural and urban, now meet the majority of their space heating needs through combustion of wood. And there are signs the shift will continue. The political and economic costs of oil imports continues to mount while each new national solar energy policy review typically emerges with a greater projected share of energy from solar sources in the year 2000.

But it would be a mistake to project blithely from the early stages of market penetration to an era when solar is expected to provide 20 or 30 percent of total energy needs. The first few percent of the market have come without concerted effort, often through uncoordinated actions of many people for whom solar's economic implications are secondary to its other aspects - psychic, environmental, and ethical. Effective planning for the next two decades requires that we account for energy producers and consumers influenced by quite a different set of motives and constraints. When we do that, it is easy to spot at least six fallacies, widely believed to be true, that now act to reduce the effectiveness of those planning programs to increase the use of renewable energy sources. In this presentation I list the six misconceptions, illustrate them with a few statistics, and then indicate their implications for those promoting solar.

Fallacy #1: Oil will be replaced by conservation, solar, and other sources in a steady progression over the next 30 to 50 years. Every single national solar study I have seen makes this assumption. But the facts suggest this country will experience a precipitous decline in oil availability within the next decade. The United States now depends on imports for almost half its oil. The political and economic strains engendered by that dependence will disrupt orderly trade well before the end of the century. Indeed CIA estimates suggest that global oil production may already have peaked out If solar implementation programs are to be effective, they must include preparations for a sudden, massive, emergency program to offset oil needs at almost any price. Without detailed solar contingency planning, there will be overwhelming pressure to push for conventional alternatives such as coal once the crunch comes.

Fallacy #2:With steadily increasing oil costs, more and more of the solar technologies will become economically attractive, and the market will produce rapid substitution of renewables for fossil fuels. Incredibly, this line of reasoning is typically based on paper studies that imagine solar energy can be sold at future prices while assuming that it is produced with labor and materials purchased at current

prices. In fact, the same forces that raise oil prices increase the costs of inputs required to manufacture, install, and service solar devices. Technological advance and rising costs for alternative energy sources will certainly make more applications of renewable energy economically attractive. But the supply curve will be very much flatter than most solar advocates imagine. To put it another way, there will be a persistent need for subsidies and incentives that supplement market forces in attracting consumers to solar. These interventions are perfectly legitimate in view of the many non-market advantages society obtains from solar technologies. But it is important not to view them as temporary expedients. They will be required indefinitely to break society's addiction to oil.

Fallacy #3: Solar Sources are clean. Most individual solar energy systems are relatively clean, but they are also small. Thus the environmental disruption they cause per BTU can still be significant in many cases. For example, airtight residential wood stoves are a major source of particulates and carcinogenic polycyclic organic molecules. Attention must be given now to the cumulative impact of many small facilities, each of which contributes little environmental damage on the margin. Current modes of environmental regulation and control are inadequate to ensure regional environmental quality from such sources.

Fallacy #4: Solar energy sources are inherently small and decentralized. The technologies of solar energy production are comparatively small, but not exclusively so. Some, such as windmill farms or hydrodams, do provide economies of scale at sizes well above that required for households or even smaller communities. But more important are the organizational aspects of scale. In their need for backup power, financial subsidies, marketing efforts, and design standards solar sources lend themselves to regulation and control by very large organizations, federal and corporate. As solar becomes a significant business, the same pressures that have consolidated brewing, food production, and car manufacture in the hands of a few very large corporations will come into play to eliminate many of the benefits sought from solar by those ideologically predisposed towards the decentralized state.

Fallacy #5: Solar sources are almost infinitely abundant. The amount of solar radiation incident on the earth's surface is enormous, but the financial cost, the materials requirement, the organizational demands, and the construction delays inherent in capturing solar energy for mankind's use effectively reduce the amount that will ever be available to very modest levels. There is certainly no chance that most of mankind can ever consume energy at levels like that in the U.S. and Western Europe today. It seems virtually certain that even the industrialized countries will be forced to reduce their energy use very significantly below current levels. Of course Western society could get along perfectly well with much less energy, if orderly preparations were made in advance. Of course they will not be. Thus solar advocates will confront a serious problem. As they place themselves in the vanguard of the transition from oil, they will bear the brunt of the frustration and even anger that will inevitably occasion society's realization that the energy binge is over. The backlash could erode much popular support for solar even though none of the other alternative sources have the potential to sustain current growth trends in energy use.

Fallacy #6: Solar initiatives can be implemented without the conflict that has come to characterize larger facilities. Most solar technologies impose on a resource base that is already extensively committed to uses incompatible with its diversion to energy production. For example, most efforts to develop small-scale hydropower facilities in New England are mired in protracted battles over issuance of the FERC license. Litigation against the dam is pursued by many different groups who seek alternative uses for the dam reservior or the downstream water flows. In one case conflict has even taken the form of efforts to fire bomb a dam installation in Maine.

Large wood-burning facilities are facing increasing resistance from adjacent landowners who object to the associated truck traffic, from bird watchers or skiers who fear the fuel harvesting will alter the character of the land, and from timber products companies who wish to avert increased competition for their raw materials. I predict that if the Navy ever gets serious about plans to locate a windmill facility on Mount Washington in New Hampshire to power the Portsmouth Naval Base, a significant contingent of protestors will decamp from Seabrook's nuclear site and head for the mountains. Energy technologies are inextricably linked with the distribution of political and economic power in this society. They alter the distribution of costs and benefits whether they are pursued on a macro or a micro scale. Society's acceptance of small solar facilities in the 1970s is no better a guide to the 1980s and 1990s than is the acquiescence to nuclear facilities that prevailed in the 1950s. Solar planners must anticipate now the potential for solar-related conflict and begin developing the mechanisms for social consensus and compromise that will be required to achieve substantial penetration of the energy markets by renewable sources.

In conclusion I wish to point out just one more misconception that might arise from my focus on the problems associated with solar energy. I am not "against" renewable energy sources. I certainly do not consider any other feasible energy sources to be more attractive. To the contrary, the professional work of my entire center is devoted to eliminating constraints on increased use of renewables. Our job would be much easier if solar advocates could become more realistic about the problems they must solve in planning regional renewable energy systems. Acknowledging the six beliefs listed above as fallacies would be a good place to start.

AN OVERVIEW REVIEW OF DISPERSED AND CENTRAL WIND SYSTEMS IN THE UNITED STATES

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NOMENCLATURE

AkWh	annual kilowatt-hours
AOM	annual operation and maintenance ($)
Capacity Credit	a capacity displacement value for WECS taken against future reserve margin requirements
COE	levelized cost of energy (¢/kWh)
Cp capacity factor	= annual energy output (kWh) / generator rating (kW) x 8760 (hours)
DOE	U.S. Department of Energy
FCR	user's fixed charge rate (%)
IC	system installed cost ($)
kW	kilowatt
kWh	kilowatt-hour
mph	U.S. miles/hour
m/s	meters/second
MW	megawatt
MWh	megawatt-hour
SWECS	small wind energy conversion systems (0.2 - 100 kW rated power)
WECS	wind energy conversion systems (>100 kW)
$	U.S. dollars

INTRODUCTION

Wind energy system activity reached a peak in the 1930's in the United States and then almost disappeared as a market due to the expansion in areal coverage of electric utilities and the attendant low costs of energy. Interest reappeared in the mid-1970's and has accelerated each year since then. The centroid of activity has been the U.S. Government Department of Energy Wind Program. In 1980, the federal budget for this program was in excess of $60 million and is expected to be about $80 million in 1981.

This paper presents a brief look at the technical, economic, and market status of wind energy systems in the late 1979 - early 1980 timeframe. It concentrates on utility and residential systems since they show signs of being the first to reach economic viability. The paper also discusses the experience of the U.S. Government trying to accelerate the commercialization of a new technology. It ends with the conclusion that wind systems are very close to being economically viable and the actions being manifested in the wind energy systems community are a sign of a successful commercialization venture.

TECHNOLOGY STATUS

Wind energy conversion systems in the United States are characterized in a number of ways. Small wind systems, ranging from 0.2 to 100 kW, for the purposes of this paper will be called SWECS. Medium wind systems range from 100 kW to 999 kW and large wind systems are 1000 kW or larger. In this paper, the medium-to-large wind systems will be called WECS.

The centroid of activity for wind system development and demonstration is the U.S. Department of Energy program (DOE). In addition, a number of industrial organizations are developing and manufacturing machines. There is also considerable activity within the electric utility industry and at the Electric Power Research Institute.

Table 1 summarizes the U.S. WECS hardware status. The MOD-0, assembled and tested by NASA in 1976, was the first intermediate-scale research turbine in the DOE program. It was followed by the MOD-0A with installations in New Mexico, Rhode Island, Puerto Rico, and Hawaii. The MOD-0A is considered a first-generation machine and not intended to generate electricity at competitive energy costs. The MOD-0A at Clayton, New Mexico has logged more than 5,000 hours of operation, generated more than 500 MWh of energy and undergone more than 12 x 10^6 loading cycles on most components. This installation has shown that a wind turbine/utility interface can be achieved with existing control and diesel generation equipment, and that routine maintenance can be provided by utility personnel (Ref. 1).

Table 1. U.S. WECS Hardware* Available or Being Developed

Machine	Manufacturer	Rotor	Rated Power (kW)	Status
MOD-0	NASA	Horizontal	100	Operating
MOD-0A	Westinghouse	Horizontal	200	Operating
MOD-1	GE	Horizontal	2000	Operating
MOD-2	Boeing	Horizontal	2500	Being Fabricated
MOD-5	Boeing/GE	Horizontal	4000+	Developmental
DOI	Hamilton Standard	Horizontal	4300	Developmental
---	Alcoa	Vertical	300	Being Fabricated
---	Alcoa	Vertical	500	Being Fabricated
165-3000	Bendix	Horizontal	3000	Being Fabricated
---	WTG	Horizontal	200	Operating
---	Energy Development Company	Horizontal	225	Operating

* as of March 1, 1980

The MOD-1 was installed in North Carolina in 1979 and is presently undergoing test and evaluation. During the design phase it became apparent that this machine

would not be cost effective, but the machine was built to gain early operating experience with a megawatt-scale system. The machine has operated synchonized with the local utility.

The MOD-2 is the most advanced machine under construction and has as its objective the generation of electricity at less than 4¢/kWh (1977 - $) when located at sites with wind speeds of 6.3 m/s (14 mph). A cluster of three MOD-2 units will be installed in Goldendale, Washington in late 1980 and early 1981.

Contracts were recently let by NASA to Boeing and General Electric for the development of the MOD-5. This machine is expected to generate electricity at less than 3¢/kWh (1977 - $) and the prototypes will be tested in late 1982 or early 1983. A similar goal and timeframe are scheduled for the U.S. Department of Interior (DOI) 4.3 MW machine being developed by Hamilton Standard in conjunction with a Swedish manufacturer.

Alcoa has developed a family of vertical axis Darrieus machines, partly with DOE funding. The machines range from 8 kW to 500 kW. Machines to 80 kW have been operated and the larger machines will be erected in 1980.

Bendix is developing a unique 3000 kW machine that will be installed in Southern California in 1980. The machine is an upwind, three-blade horizontal axis design using hydraulics to convey the power to the ground, and the entire tower rotates to yaw the machine into the wind. A smaller prototype has been in operation for several years.

WTG, Inc. has installed a 200 kW unit on Cuttyhunk Island, Massachusetts and recently sold a similar unit in Nova Scotia. Energy Development Company has a number of units in service, ranging from 45 to 225 kW and reportedly has a megawatt-scale system under development.

There are a number of small machine manufacturers currently developing and/or marketing SWECS in the United States. These range from a 0.2 kW system to 100 kW and the current market is estimated to be approximately several hundred units per year (Ref. 2). In addition to the current off-the-shelf hardware, DOE is sponsoring multiple development contracts for 1-4-8-40 kW systems. These systems will undergo extensive testing at the DOE Rocky Flats Test Site in the 1980-1981 timeframe. DOE feels that one more development cycle will be necessary to achieve the DOE cost goals for SWECS. While technical feasibility of WECS and SWECS have been demonstrated, technical maturity of the products have not been demonstrated (Ref. 2).

ECONOMIC STATUS

Wind system economics are being evaluated with two different methodologies. The Cost of Energy (COE) approach establishes the levelized cost of energy from the turbine based upon the initial cost, annual costs, annual energy output, and the user's financial characteristics, as shown in Equation (1).

$$COE = \frac{(IC)\ (FCR) + AOM}{AkWh} \qquad (1)$$

This represents a stream of levelized annual costs that have the same present value as the stream of annual costs the machine will experience over its assumed life-cycle. This is a methodology used in the United States by utilities to compare alternative generation options.

A second methodology, called the Value of Energy, is to calculate the present value of the stream of conventional energy costs that will be displaced by the wind turbine over the assumed life-cycle and use them to calculate the breakeven installed cost that could be incurred for the wind system. If this breakeven cost is then used for IC, in Equation (1), this results in the levelized value of energy that would represent the breakeven case. This value of energy could be considered to be the cost goal.

Figures 1 and 2 show the DOE cost of energy trends for intermediate and large-scale wind systems. Also shown are the DOE cost goals for specialized cases, useful markets and wide-scale use (Ref. 3). The DOE development program was designed to yield economically viable machine designs for intermediate class by 1986 and megawatt-scale by 1983 - provided that the designs are manufactured in quantity.

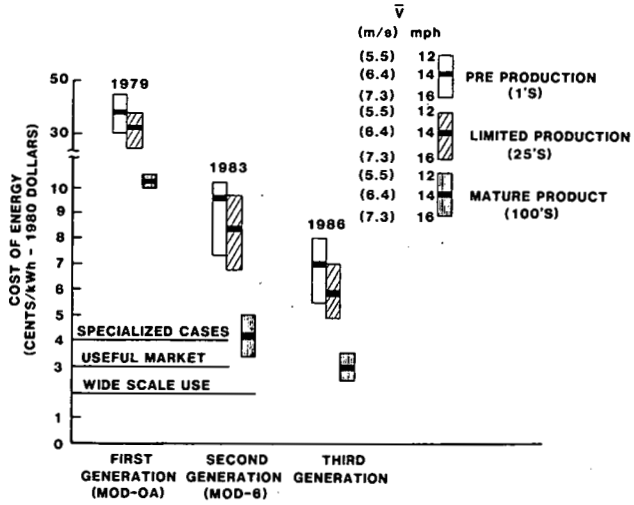


Figure 1. Cost of Energy Trends - Intermediate Wind Sytems (DOE Horizontal Axis Designs)

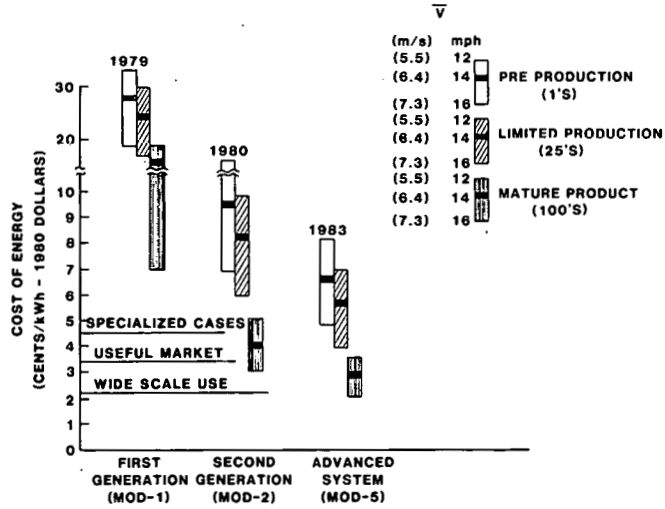


Figure 2. Cost of Energy Trends - Large Wind Systems

The cost of energy was developed using Equation (1), a fixed charge rate as shown in Table 2 (Ref. 5), an annual operation and maintenance cost of 2% of the system initial cost, and the appropriate annual energy output for each machine (assuming a 90% machine availability).

Table 2. Components for Levelized Fixed Charge Rates

Total Return (weighted cost of capital)*	10.00%
Depreciation (sinking fund)*	0.61
Allowance for Retirement Dispersion	0.56
Levelized Annual Income Tax	4.70
Levelized Annual Accelerated Depreciation Factor	(1.98)
Levelized Annual Investment Tax Credit at 10%	(1.68)
Property Taxes, Insurance, etc.	2.00
With Tax Preference Allowances, Total	14.21%
Without Tax Preference Allowances, Total	17.87%

*The total return plus sinking fund depreciation equals capital recovery factor for a life of 30 years and 10% interest = 10.61%

Figure 3 shows the DOE SWECS cost of energy trends and the DOE SWECS cost goal (Ref. 4). These trends were investigated in detail on a recent study (Ref. 2) and Figure 4 shows the results for the 4 kW size. The costs were developed using a fixed charge rate and operation and maintenance cost totaling 15% plus the annual output of a representative 4 kW design, operating in a 14 mph average annual wind speed that exhibited a Rayleigh distribution. Table 3 summarizes the values used to establish the fixed charge rate.

The figures show that, for the assumptions made, megawatt-scale WECS and 4 kW residential SWECS would both generate electricity for their respective users at a levelized cost of about 10¢/kWh (1980 - $) in preproduction quantities. Intermediate WECS, as shown in Figure 1, would generate electricity at about 30¢/kWh. However, there are non-DOE horizontal axis designs as well as vertical axis designs of intermediate-scale, that are advertized to generate electricity at substantially less cost. Table 4, based upon manufacturers' literature, is an example. Whether the difference is due to company pricing policies, a difference in product reliability, or other reasons, cannot be ascertained at this time. It is clear, however, that industry hardware standards would help to assure consistent quality and help to assure that similar products are being compared.

It must be concluded that the technical status of wind systems, at this writing, is developmental. Within the next year, as test results on SWECS become available from the DOE Rocky Flats Test Center, data is developed on four MOD-0A machines, the MOD-1 becomes operational, three MOD-2 units become operational, numerous non-DOE design machines are erected, the Bendix machine becomes operational, etc. - this may change.

To this point the results of the levelized cost of energy have been presented. The next section deals with the value of energy analysis. This second economic

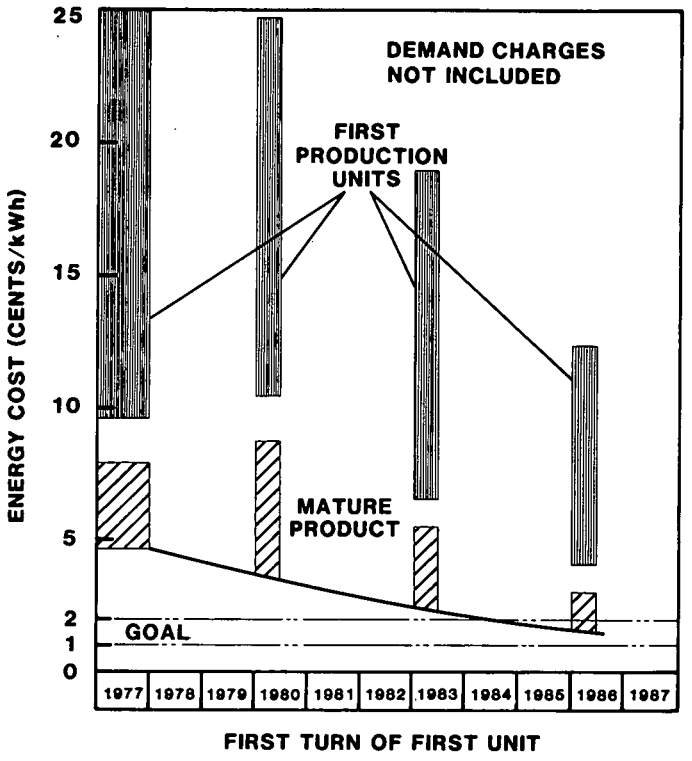


Figure 3. SWECS Cost of Energy Trend

Source: 1978 Wind Energy Program Plan

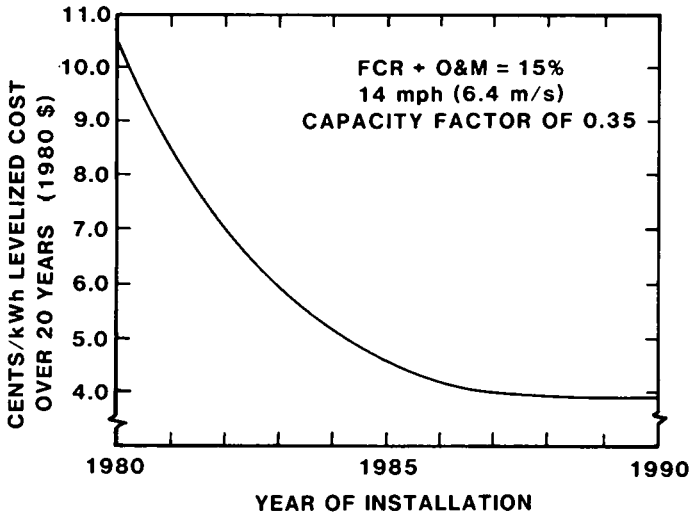


Figure 4. 4 kW Residential SWECS Cost of Energy Cost Trends
(Including a Tax Credit of 22% of the first $10,000)

Table 3. Summary of Values for SWECS Economic Analysis ($ - 1980)

Annual General Inflation Rate	6% (constant over SWECS life)
Sales Tax	5%
Annual O&M Cost/Capital Cost	2%
Annual Insurance Cost/Capital Cost	0.5%
Loan Interest Rate	10%
Loan Term	20 years
Marginal Federal Income Tax Rate	25%
Discount Rate	10%
Property Tax	0%

Table 4. Alcoa* Vertical Axis Cost Summary Data (late 1979 - $)

Alcoa Model	Rating (kW)	Installed Cost	Levelized Cost of Energy (¢/kWh)		
			(5.5 m/s) 12 mph	(6.4 m/s) 14 mph	(8.2 m/s) 18 mph
#1238229-300kW	300	$170,000	10.5	5.4	3.6
#1238229-500kW	500	$190,000	14.3	6.0	3.4

* Based upon Alcoa literature.

methodology being employed uses hourly wind data and a specific wind system characteristic curve to calculate the time series of wind energy output. This time series is then compared to an hourly load time series to establish the savings that a user would experience from the wind. The methodology has been described in detail in an earlier paper (Ref. 6). The present value of the savings in conventional energy costs due to the wind system are then used to establish the breakeven cost, or breakeven value, of the wind system (its allowable initial cost). The breakeven cost can then be used in Equation (1) to establish the levelized breakeven value of energy. If the analysis is done for installations over several years, and the results compared to the cost of energy trends, the year in which economic viability could occur can be estimated.

A recent study (Ref. 7) compared the results of most of the utility-WECS analyses that have been conducted in the United States, after normalizing them to repre-

sent a consistent set of assumptions. Figures 5 and 6 show the breakeven installed cost for the first WECS, resulting from the normalization of the original study results. If these initial values are converted to their equivalent energy costs using Equation (1), the values in Table 5 are obtained. NEPOOL (the New England Power Pool) values represent the "average" for all of the utilities analyzed and HECO (Hawaiian Electric Company) represents the highest WECS value found in the United States to date. HECO is 100% oil-fired and has a calculated capacity factor of 0.59 for the MOD-2 WECS. If the values shown in Table 5 are compared to the cost of energy trends in Figure 2, it is apparent that economic viability for megawatt-scale WECS could occur for the MOD-2, as a mature product, in the early 1980's and for the MOD-5, in limited production, in the mid-1980's. A mature product MOD-5 would appear to have a potential for wide-scale use in the mid-to-late 1980's.

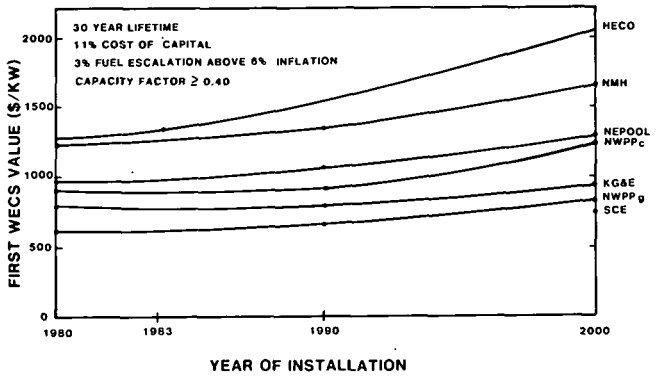


Figure 5. First WECS Value for Different Installation Years Normalized for Economic Parameters and Capacity Factor (Fuel Displacement Value Only) ($ - 1977)

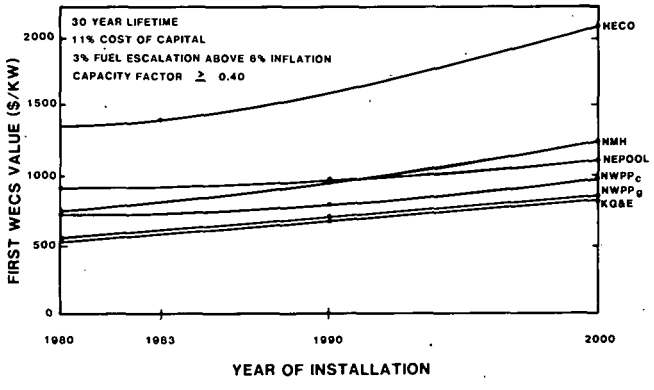


Figure 6. First WECS Value for Different Installation Years Normalized for Economic Parameters and Capacity Factor (Fuel Displacement and Capacity Credit) ($ - 1977)

It should be pointed out that, while Figure 6 and Table 5 indicate a higher value for WECS if a capacity credit is taken, this may no longer be the case. Recent studies by JBF, as yet unpublished, indicate that some U.S. utilities have their equipment mix skewed significantly off-optimum due to the recent rises in fuel prices. Because of this, their future expansion plans call primarily for baseload equipment. If a capacity credit is taken for WECS, even at modest penetrations, this results in higher fuel costs for the remaining mix. The high fuel costs can actually result in a negative value for the capacity credit. This hypothesis has been tested on several utilities and found valid.

Table 5. First WECS Breakeven Cost and Levelized Value of Energy for New England Power Pool and Hawaiian Electric Co. ($ - 1980)

		1980		1990		2000	
		NEPOOL	HECO	NEPOOL	HECO	NEPOOL	HECO
Fuel Saver	$/kW	951	1835	1077	2130	1330	2740
	¢/kWh	5.4	7.0	6.1	8.1	7.6	10.4
Fuel and Capacity Credit	$/kW	1217	--	1357	--	1690	--
	¢/kWh	6.9	--	7.7	--	9.6	--

Note: Three to four digits does not imply that number of significant digits - for computational purposes only.

The values in Table 5 can also be used as an input to obtain an estimate of the time in which residential SWECS may become economically viable. The DOE program plan (Ref. 4) indicates that the value of SWECS to a residential user will most probably be established by the value of the fuel used to generate residential electricity. That is, any fixed costs associated with generation and transmission/distribution will still exist if the user remains tied to the grid. Table 5 shows the levelized fuel value assuming that oil prices will increase at 3%/year above inflation. If the fuel values are levelized for other escalation rates (above inflation) and plotted on the graph with the 4 kW cost of energy trend (from Figure 4), the results in Figure 7 are obtained. The figure suggests that residential SWECS in the United States (at least those areas having utilities with significant oil-fired generation), should become economically viable (on a 20-year life-cycle basis) in the early-to-mid 1980's - if DOE achieves its SWECS program costs for energy from residential wind turbines. It should be noted that the results presented here are for the NEA 22% residential tax credit. The new 40% credit will accelerate the market even more. However, the tax credit is due to expire in 1985.

For the assumptions made in these analyses, it appears as though both megawatt-scale and residential-scale wind systems are within a factor of two of economic viability and can reach full viability about the mid-1980's. Industrial/commercial market will probably emerge later, due to the investment criteria used (e.g., 3-5 year payback). It mut be stressed, however, that economic viability presumes that the wind turbine will last for the lifetime assumed, will operate reliably with the assumed operation and maintenance costs, etc. - this has not been demonstrated as yet.

MARKET STATUS

This section initially addresses non-DOE market activity as it existed in early 1980 and ends with a discussion of wind energy commercialization. Privately funded hardware development activities in the United States are initiated by individual

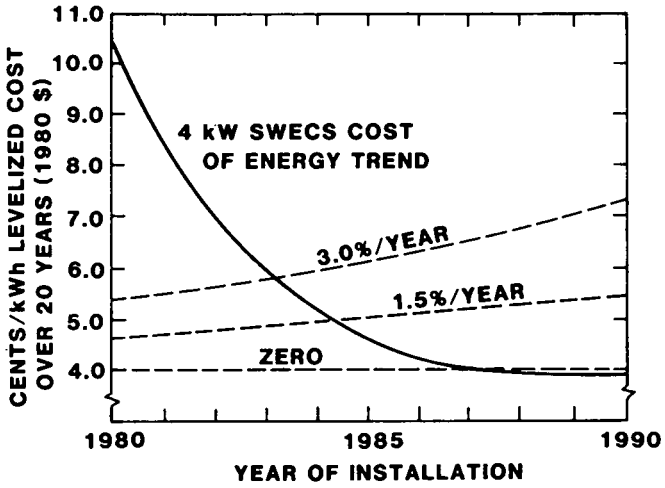


Figure 7. 4 kW SWECS Modified Cost of Energy Trend and Utility Value of Fuel Displaced at Different Escalation Rates of Fuel Value Above Inflation (Including Tax Credit of 22% of the first $10,000)

inventors, small businesses, and large corporations. There are approximately 45 firms engaged in SWECS and WECS production and marketing, the majority of which are small businesses. These manufacturers offer more than 80 different machines ranging in size from a fraction of a kilowatt to several megawatts in rated output. It is difficult, however, to quantify the nature or extent of the market activities that are being pursued by these manufacturers. This stems from the fact that the market is just emerging for some applications, but more importantly, most of the marketing organizations consider this information proprietary. The following picture emerges, based on interviews and published data, early in 1980.

A significant market has existed for many years, primarily in agricultural water pumping applications. A modest commmercial market also exists for small wind turbines that are used to supplement remote residential battery charging, for experimental and educational activities, and on sailboats. One company in the midwest has been serving this market for 30 years and sells 700 to 1,000 0.2 kW machines per year.

The majority of private SWECS hardware development activity is characterized by small firms building 1 to 8 kW machines for the residential market. A New England firm has been selling 1 to 4 kW machines in this marketplace and advises that they have an extensive backlog. Other manufacturers in New England, Pennsylvania, the Midwest, and California indicate similar experiences. It should be noted that it does not take many orders to saturate the manufacturing capability of most of the small machine manufacturers. The current industry volume is quite small, perhaps several hundred machines per year, but undoubtedly less than 1,000 in addition to the 0.2 kW market mentioned above. Small machine sales apparently are not being made for classical economic reasons. The residential owner is not enjoying a positive cash flow and will not "breakeven" over any reasonable period of time. The bulk of residential WECS owner's electricity is still provided by a standby generator, tie to the utility grid, or other power source. The SWECS industry is in the precursor stage of market penetration. Full market emergence will require viable economics or a change in the perceived value of wind energy to the user (reliability, independence, etc.).

The preliminary market is providing support for a number of entrepreneurial organizations, some of which appear to have little other visible support. Most of these firms have limited product lines, typically one or two machines at a time.

Limited financial resources constrain their hardware design and development efforts considerably. Plans to expand the product lines are, therefore, contingent upon customer orders. They also indicate uncertainty as to their ability to raise capital to expand their manufacturing base, should this be necessary. With large firms entering this marketplace, the future for many of the small manufacturers appears uncertain. In spite of this, many of the firms exhibit a strong independence and little desire to merge with larger firms. This is counter to the trend a decade ago when many small, high-technology firms often measured success by how much the company could be sold for.

The hardware production capability of firms addressing the residential market is also limited by their mutual dependence on a few suppliers of specialty components. Customer orders would, in this case, act as a second production stimulus to assure adequate supplies of synchronous inverters, alternators, control mechanisms, and other key components. The demand for these items has been so small that there has been minimal trouble in obtaining desired quantities. The ability of specialty component manufacturers to meet the near-term demand for their products appears certain. There is, however, some doubt as to their ability to respond to a sharp increase in demand at this time. In at least one instance, a SWECS manufacturer is dependent on one of its competitors for blades.

Several small machine manufacturers are finding outlets for their hardware overseas. Two New England firms reported sales and/or contract negotiations in progress with countries in Europe and Africa. Activity in this regard is encouraged by the potential for international financing and the currently unfavorable SWECS economics domestically. The main thrust of near term SWECS hardware development will, however, most likely continue to be in the 1 to 15 kW residential and small farm markets - for domestic use. Until the products are fully developed, most manufacturers indicate they will not pursue international markets.

A very modest market is evolving for machines larger than residential size but less than megawatt scale. With some exceptions, this marketplace is being pursued by larger firms than those described as small businesses addressing the residential market. A number of machines in the 25 kW to 500 kW range have been sold to educational, industrial, institutional, municipal, and utility users. One firm reported orders for several machines in the 300 to 500 kW size range. Production capability for this firm is projected to be two machines per month by late 1980. Other intermediate-scale manufacturers report present production capabilities of from 10 to 20 units per year. With the exception of rotors, some intermediate-scale WECS manufacturers claim to use off-the-shelf components. It is possible that all but the larger firms will experience cash flow and capitalization difficulties similar to those of the small hardware manufacturers, if this market accelerates.

Most of the intermediate-scale WECS manufacturing activity is by medium-to-large firms. Two large corporations either have plans to, or will, enter the intermediate hardware market with vertical axis designs. One intermediate hardware developer reports a manufacturing capability for 40 to 225 kW machines at present. The present U.S. market for intermediate-scale WECS appears to be uncertain, and no published market surveys are available. For this reason, intermediate-scale WECS developers have welcomed inquiries from Australia and countries in Africa and the Caribbean. Several manufacturers have submitted proposals for machines. No contracts have been awarded as yet, but at least two are currently being negotiated. There is a major activity underway by a New England firm that is marketing power to the State of California. They plan to have a farm of 20 machines (50 kW each) operational in New England in 1980. This demonstration will be followed by a large array in California. The most encouraging feature of this plan is its ability to

attract investment capital. A "third party" arrangement was employed, whereby private investors purchase three 50 kW machines. The machines will then be "leased" back to the seller who will operate and maintain the machines, sell power to the State of California, and provide a cash flow to the investors. The only federal involvement would be via legislative incentives such as short-term depreciation and higher investment tax credits. This third party arrangement is primarily a method to reduce the technical risk to the end user, prior to technical readiness being demonstrated, and place it on the venture capital community, where risk is endemic.

Megawatt-scale hardware development in the private sector is being conducted by a firm in Washington state. The Washington firm has sold a 3 MW system to a West Coast utility. The machine is not operational at this writing. It would be inappropriate to suggest that a megawatt-scale market has emerged, at this time, in the United States.

Other activity has lead to joint ventures in the United States with Swedish megawatt-scale machine manufacturers. Several large firms in the U.S. are doing market research prior to entering the large WECS field. At least one of these firms reported contact and interest from overseas, as did one of the present manufacturers.

As in the case of intermediate-scale WECS, third-party arrangements are being pursued to set up an 80 MW WECS farm in Hawaii. The megawatt-scale machines will provide electricity to the Hawaiian Electric Company.

The non-DOE activities described above are precursors to the establishment of economically viable mature markets. In general, large firms are developing small, intermediate, and large-scale wind turbines. Small firms appear to favor the small residential and farm markets while medium-to-large firms go either way. Many of the small-to-medium firms are showing signs of strain in terms of their ability to manufacture and service machines, and acquire capital to expand. A fragile infrastructure to support the emerging markets is being established. There is every indication that the industry will continue to strengthen as a function of conventional energy price escalations and legislative incentives.

Wind energy will probably be the first solar electric technology to become economically viable, thus it is in the forefront of the DOE commercialization activity. Its evolution can be explained with the aid of the phase descriptor diagram shown in Figure 8. It suggests that three phases are involved in commercializing a new technology. In Phase I (the 1970's) wind energy costs were substantially above the cost goals. Equipment costs were high; only a novelty market existed; the primary inputs were provided by experimenters, engineers, and technical personnel; no production capability existed; reliability was not critical during this research period; economics were something to consider in the future; and there was no concern as to how precisely the DOE cost of energy or cost goals were defined. This clearly was an activity that the U.S. Government could step into and play a leadership role.

As the hardware began to mature, and the cost of energy from wind systems decreased, the level of activity in the wind community increased. This led to Phase II (cost of energy and cost goals within a factor of 2-3) and a new set of characteristics emerged within some parts of the wind community. These were manifested as substantial entrepreneurial activity; technical personnel still in control, but business management personnel becoming more involved; the entrance of a number of manufacturing firms into the area; evolution of a specialty market served by limited production capability; economics becoming more important; cost goals being carefully scrutinized; the government's role starting to change from develop-

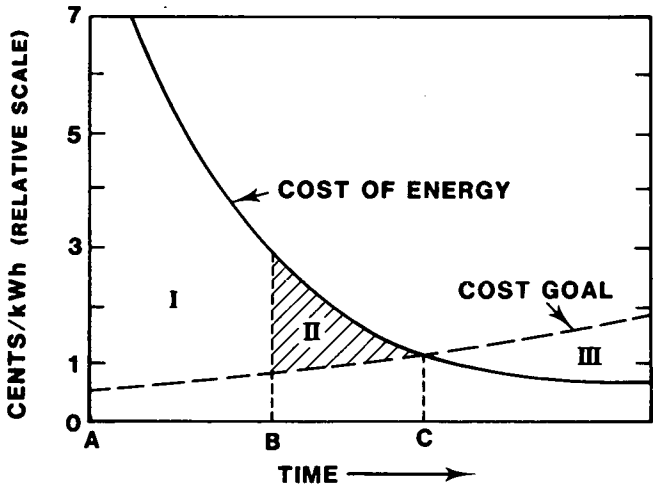


Figure 8. Commercialization Phases for Alternative Energy Systems

mental to commercialization; and significant stresses introduced by vested interests, each from their own point of view.

Phase III will be a period that is characterized by economics being critical, reliability being required, full production, low stresses at the government-industry interface, and the government's role being primarily component research and addressing institutional issues.

Wind energy is now entering Phase II and is exhibiting all of the stresses that would normally be associated with the commercialization of a new product, compounded by the stresses associated with the U.S. Government's attempt to accelerate the process. Thus, the polarization being experienced in some parts of the wind community is an indication of the progress being made in commercializing this new technology. That is, it is a precursor of a successful program.

CONCLUSIONS

- Residential SWECS and utility WECS would currently be within a factor of two of economic viability, based upon life-cycle analysis, for those regions that have good winds and a significant component of oil-fired equipment in their utilities - if purchasers could be assured of the performance and lifetime of the hardware.

- While the technical feasibility of wind systems has been demonstrated, the technical maturity has not.

- The paucity of test data on current wind systems, coupled with the lack of hardware standards, has led to stresses within some parts of the DOE non-DOE wind community. This has been compounded by rapid escalation of conventional energy costs. There is simply no evidence to support claims of technical maturity or economic viability of existing, off-the-shelf hardware manufacturers - but there most probably will be in 2-4 years.

- The combination of escalating conventional energy costs and decreasing wind turbine costs will lead to an economically viable market substan-

tially earlier than anticipated. The uncertainty in the future behavior of both of these trends suggests the strong need to continue the U.S. Government development and demonstration role for several more years.

- Indications are that utility wind systems will be considered primarily as fuel savers, in the near term, for many utilities. This is a direct result of the negative value resulting from taking a capacity credit in utilities that are planning baseload expansion, since it results in burning more expensive fuel at times when there is no wind. This may not be the case for utilities that do not burn oil or gas.

- A market is beginning to emerge for wind systems in the United States, but it is a specialty market, stimulated by government activities and legislative incentives. Emergence of a major market will require demonstrated technical maturity of the product, economic viability with conventional energy sources, and/or changes in the user's perception of the value of wind energy (e.g. political, social, psychological value).

This paper was written in the late spring of 1980 and the data, thoughts, and conclusions are representative of that timeframe.

ACKNOWLEDGEMENTS

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NEW DIRECTION IN THE U.S. SOLAR PROGRAM

Dr. Frederick H. Morse, Acting Director
Office of Solar Applications for Buildings
Conservation and Solar Energy
Department of Energy
Washington, D. C.

At 715 SW Morrison Street, Portland, Oregon, there stands an older ten-story office building which looks like any other in the downtown area, inside and out. Two floors of this building are occupied by the Western Solar Utilization Network (WSUN), the Regional Solar Energy Center serving the Western United States. Their tastefully decorated offices occupy 9,000 sq. ft. and pleasantly surprise the visitor by their even, shadowless lighting and a total absence of the fluorescent lights so common in offices across the country. More importantly, WSUN will get a rebate check of some $6,000 from the landlord this year, something the occupants of the other eight floors will not receive. The check is for the electric bill the building's owners did not have to pay because of the way WSUN remodeled their offices before they moved in. For, in addition to the usual ritual of erecting partitions and redecorating, WSUN included energy features of their own design. These include a fan assisted hybrid collector/distribution system using all south-facing, double-glazed windows, equipped with special blinds, to collect solar heat, provide increased daylighting, and natural cooling; daylighting partitions, insure both the distribution of natural light and privacy for the occupants. The office is equipped with indirect lighting with energy saving central control, activated by available natural light; supplemented by task lighting, where needed. There is a provision for performance monitoring of this system. For comparison, two other floors of the same building having conventional energy systems, will also be monitored.

Results:

- Air conditioning was seldom used, in spite of the unusually warm first summer of operation.
- Estimated total annual energy savings of 150,000 KWh of electricity are predicted. This will result in a reduction of operating expenses by some $6,000 a year.

Costs: The energy features cost $70,000 including $32,000 for light fixture modifications. The total cost of remodeling was $208,804, of which the building owner's contribution amounts to $80,280.

Secondary Benefits:

- The lighting system features contractor-modified standard light fixtures (cost of modification approximately $32,000). As a result of the success of the system, however, the manufacturer now offers the modified fixtures as one of his standard line items. Consequently, the cost of a similar retrofit project would be reduced, nearly cutting these costs in half.

- Over 120 architectural and engineering firms visited and studied the system so far.

- Demonstration of a working retrofit solar system in an average commercial building - replicable in many locations across the country.

- Two new office buildings already incorporate these energy saving features, even though the system is less than six months old as I speak these words.

In Cedar Rapids, Iowa, there stands an attractive, new three-bedroom home with an attached two car garage. The owner of this house will save 90% of the energy bill his neighbor pays in a house which looks the same inside and out, and has the same 1,200 sq. ft. floor area. This energy saving house is one of twenty winning models designed as part of a design competition sponsored by DOE's Office of Solar Applications for Buildings, through the Mid-American Solar Energy Complex (MASEC), the Regional Solar Energy Center for the mid-Western states. Fifty percent of the energy savings are provided by passive design features, including four large south facing windows, thermal mass, and a generous overhang to block out the summer sun. The remainder is the result of a variety of energy conserving features.

Results:

- 90% energy savings compared with conventional construction for similar homes, reducing auxiliary heat requirements to 1.0 BTU/sq.ft./degree-day.

- Annual heating oil consumption in the local climate is approximately 80 gallons.

Cost: The $27,500 design cost was paid for by the Solar Applications for Buildings program. Also included in this figure is the cost of several workshops and open houses, the production expenses for sets of building drawings which are now commercially available, and the cost of information dissemination and publicity about the project. The $56,000 construction cost for the house was exclusive of the lot. Normal private sector financing was used.

Secondary Benefits:

- Home sold quickly; design is in demand: at least eight similar homes are already under construction throughout the region.

- Four Votech School workshops were held featuring the design; most future skilled construction craftsmen are trained in these schools.

- Additional workshops were co-sponsored by local chapters of the National Association of Home Builders, providing further trade exposure.

The Cedar Rapids, Iowa model home is but one of twenty winning entries in the MASEC design competition called "Solar '80". All homes feature low auxiliary heat loads. Many of them have been built, some in multiples, or are in various stages of planning or construction. Prices range from $55,000 to $110,000, exclusive of lot price, and the houses have the appearance of a typical single family tract home. None use exotic materials or custom

building products. Several of the homes were built for the speculative market and sold without delay or difficulty.

The "Solar '80" program includes a number of multiplier features such as workshops, open houses in the newly built models, magazine and media coverage, and heavy involvement by the region's Votech Schools. Construction plans for these buildings are now available for commercial distribution by MASEC and are much in demand.

The program's success contributed significantly to the decision by Iowa's Governor to recommend state legislation requiring a 50% reduction in energy demand for all new housing by 1985. The program also provided impetus to the Minnesota Housing Authority's offer of 7% financing in a $13 million program for qualified applicants wishing to construct energy conserving homes with heat loads of 3.0 BTU/Sq.ft./degree-day or less.

On June 27, 1980, the manager of solar water heater program of the Northeast Solar Energy Center (NESEC) was invited to speak at a press conference sponsored by the solar division of a major U.S. corporation. After the conference, reporters and the feature speaker inspected the solar water heater installed on the roof of the building. Two months later the company informed NESEC that as a result of the publicity received, the company had sold, within a single month after the press conference, 73 solar water heaters in the Springfield, Massachusetts area. Since then, this company regularly consults with NESEC on both technical and marketing issues.

This is an example of the many ways - small and large - that DOE's Solar Applications for Buildings program assists business in developing solar products and the market in which to sell them.

Chelmsford, Massachusetts will have a new town office building in December. It used to be an unoccupied schoolhouse which the town's selectmen decided to convert to house the municipal government. For the conversion, the used $30,000 in town funds and a $700,000 Economic Development Administration grant to refurbish the old building. The selectmen and their architect heard about energy conservation and solar energy and were considering building a Trombe wall as part of the refurbishment effort.

Enter the Solar Applications for Buildings program, represented by the technical support staff of the Northeast Solar Energy Center. At the request of the selectmen, the NESEC people explored, together with the town fathers and their architect, the various conservation and solar options suitable for the building, and assisted in drawing up plans for the energy features.

The Trombe wall idea was replaced by a more suitable combination of daylighting features, proper shading to reduce cooling loads, and a functional sunspace. These features reduce electric lighting requirements to nothing on sunny days, and to a small fraction on cloudy days. Installed cooling capacity was reduced by 50% with the heating load also significantly reduced.

Results:

An estimated 500 to 600 gallons of oil will be saved during each heating season. Projected savings in the use of electric cooling approximate 1,000 gallons of oil per year; with another 1,000 gallons of oil savings contributed by daylighting. Total annual savings: 2,600 gallons of oil equivalent.

Cost: The equivalent of less than one-man week of time was spent by NESEC technical support personnel: approximately $1500. Town funds of about $30,000 and the $700,000 EDA grant, part of which was used to include the energy features. These would not have been included, were it not for NESEC's contribution.

Secondary Benefits:

- The Energy Committee of the Town of Chelmsford requested further assistance in analyzing energy saving and solar opportunities in the town's other public buildings.

In Brunswick, Maine a local contractor built a 10' by 16' sun space, onto an existing family residence. Since the sun space was added, the fuel consumption of this home was reduced by 50%. The design was so successful that 10 similar additions have sprung up to date throughout the Brunswick area and over 400 sets of plans were provided to inquirers from across the United States. This simple but effective design was developed as part of a regional market development plan for solar energy conceived by the Northeast Solar Energy Center and implemented by the Brunswick entrepreneur under a $12,000 NESEC contract. The package included the design and construction of the prototype sun space, monitoring its performance and an extensive information dissemination program. The prototype was featured in several national home design and improvement publications as well as the general press.

The Society For The Protection Of New Hampshire Forests will soon occupy its new headquarters, a new 8,000 sq. ft. building attached to an existing 2,000 sq. ft. farmhouse. The building features a direct gain passive solar system with phase change thermal storage incorporated into the ceiling, improved daylighting, and a solar water heating system. The design was developed by the building's architect, on the basis of technical guidance regarding the energy features, provided by the technical support team of the Northeast Solar Energy Center.

Results: The building will receive 56% of its heating needs from solar energy. In addition, 75% of the energy used for water heating will also be provided by the sun. The daylighting features provide 70 to 150 foot-candles of light for the workrooms and 30 foot-candles to the offices on overcast days. This equals standard lighting levels for similar applications which means that daytime use of artificial lighting is not necessary. The backup system is a woodburning furnace. The Society's objective was to reduce backup energy demand to a level which would - when the concept demonstrated by this building is extended to all of the state of New Hampshire - make it possible to rely on the waste wood provided by the state's extensive forests.

Costs: Design guidance provided by DOE, by way of the NESEC technical support team, cost $1500. A $75,000 DOE construction grant paid for all of the solar features. The total cost of the building was $500,000, provided by private donors and matching foundation grants.

Secondary Benefits:

- The DOE funded phase change storage ceiling is the first commercial, office scale application of a concept which was developed and tested at the MIT Solar House Number Five. The product used is a low-cost, high performance version developed commercially by a private corporation. This product is now available for use in other buildings.

- High visibility and good publicity for solar energy - and to the energy saving products used - include unsolicited media coverage and an exhibit of the building's model in a downtown bank. The building now serves as a model for other office buildings within the region.

The technical support staff of the Northeast Solar Energy Center, three professionals, has been in substantive contact with 1,200 professionals and multiplier contacts so far during 1980. As a result of this interaction, the awareness and experience level with energy conserving and solar energy systems of over 1,000 professionals has been enhanced; and several hundred new or redesigned passive buildings have been started in the region's ten states. The resulting publicity about solar energy systems has reached several hundred thousand people.

Technical support provided on an individualized, one-on-one basis is an expensive, but effective and necessary service. The use of so-called multiplier contacts has the potential to reduce these costs significantly when distributed on a case by case basis.

Similar technical support services are being provided by all four Regional Solar Energy Centers. The RSEC's in turn, rely on the research and analytical backup provided by the Solar Energy Research Institute (SERI) and several of the DOE laboratores such as LASL, LBL, ANL, BNL.

The foregoing are but a handful of examples of the way the Solar Applications for Buildings program operates and an indication of the local achievements of the program throughout the United States. These projects also serve to illustrate the potential impact of these kinds of activities on the solar and conservation products market and industry.

Needless to say, these activities could not be successful without the vital technical base provided by an extensive research and technology development program, and a broad range of market development, information and regulatory programs, all of which form the Solar Applications for Buildings program.

Solar energy first appeared officially in the Federal government in 1971. Let's take a quick look back at what has happened since then, and let's do it from a Federal government perspective. One cannot speak about the national solar energy program for building applications without establishing the environment in which the overall solar program was initiated and which influenced its early growth and development. Some highlights follow:

- To the first assessment of the potential of solar energy as a national resource, it was concluded that there is no technical reason why 20% or more of the nation's energy needs couldn't be supplied by solar by the year 2000. Several years later the Domestic Policy Review arrived at the same conclusion. How much will actually be supplied will depend on the degree of national commitment to the development of a solar market out of the energy needs which exist in all fifty states and the development of solar products to fill those needs.

- Budgets were prepared and the Solar Program was initiated. Initially these programs were organized by technologies: active and passive solar heating and cooling, agricultural and industrial process heat, photovoltaics, solar thermal power systems, wind, biomass and ocean thermal energy systems. Later, a functional organization, more responsive to the way industry operates, was initiated. A vast array of studies were made and hundreds of contracts were let. A technology base was built via unsolicited proposals, RFPs, PONs and PRDAs.

- Solar related bills were passed - all were supportive, some were timely, others were counter-productive.

- The National Solar Energy program first began in NSF, then was moved to ERDA, then to DOE, under an ever changing management structure.

- The Solar Energy Research Institute and the Regional Solar Energy Centers were created and began to function. Today, after a rather difficult beginning, I see these organizations as the leading edge of the solar program and a key to its success.

- A solar industry was born - first dedicated mainly to medium temperature water and space heating systems, and more recently, expanding to include passive, photovoltaics, and wind and biomass systems. And, as this infant industry suffered the expected childhood diseases, the Federal government program progressed through its own learning curve, slowly growing out of its technology oriented infancy, through a functional organization phase, to its present stage of maturity where it is designed to respond effectively to the real and complex needs of the energy market.

- Public interest in solar and renewable energy grew, citizens groups were formed and began to express their views, and local initiatives sprang up across the land and demonstrated the ability of communities, large and small, to remove the institutional and informational barriers that limit the rate at which the solar buildings market will be developed.

- Many government agencies besides DOE itself began to conduct their own programs in response to widening public concern with energy issues, or formed new cooperative ventures with DOE.

- Although solar began to attract private capital, financing emerged as a crucial need of a new conservation and solar oriented national energy approach. New incentives were legislated on the federal, state and local level.

In most areas of the United States solar is now a viable and economically attractive energy option for a variety of applications. Its attractiveness will grow as fossil fuel costs continue to rise, financing becomes more easily available, and more state and local incentives are put into effect, and more and better solar products appear in the marketplace.

If this is so, why then is there a need for a DOE solar program? And if there is such a need, what should be the future direction of DOE's program?

The main reason for continuing government support for solar is, of course, that we must accelerate the rate at which renewable energy alternatives are developed to replace dwindling and increasing expensive conventional supplies. The world of 1980 is a very different world from that of 1971. The rising cost of all conventional fuels is a constant painful reminder of this difference. Today, energy - once a seemingly minor and very much taken for granted aspect of our lives - is an issue that seems to inescapably effect everything we do. It figures in a major way in inflation and economic policy, the cost of everything from groceries to manufactured goods, to maintaining a home or renting an office. It permeates the job market and affects the stability of communities. It ties in with hunger and aggravates social problems in ways too numerous to mention. Energy today is a cornerstone of a very fragile peace and the thread by which may well hang the political power balance of the world.

In short, we can't wait. This is not a "business as usual" situation in which we, as a nation, and as members of the community of man can continue to pass the responsibility from industry to citizens, to governments, to politicians, and back to industry and the citizen. The situation calls for national leadership uniting all the various organizations into one national program in which the government's role does not undercut the forces which operate in a free market, but gently and firmly, nudges these forces in the direction of permanent, long term, responsible solutions; a national program that helps accelerate the processes by which a free economy is capable of solving its energy problems.

This brief history of the solar program reflects the changes to which we have had to respond. From a small, almost leisurely beginning in the early 70's when the solar program simply responded to the ideas of scientists who submitted unsolicited research proposals, the program was suddenly thrust into national prominence by the congressional mandate to demonstrate solar heating and cooling for buildings. And demonstrate we did - a technology which was indeed understood, but embodied in products which were for the most part not ready for the market. We learned this distinction. We realized that accelerating the commercialization of solar would require a complete understanding of how industry develops and markets products. We correctly recognized the need for a midwife to the infant solar industry and saw both grow in spite of many early illnesses. We learned many lessons. As a result, our approach was refined. Our first orientation towards technology development expanded to include market development. Technology research alone would not result in energy displacement. A very fragile and very vulnerable solar industry was emerging to manufacture, sell and install solar equipment. DOE had to find ways to support and assist that industry until it could become fully self-sustaining. So, the program was re-oriented to better support each of the steps by which industry invents, develops, markets, and services products.

DOE learned other things. Somehow, we ended up supporting an industry that was too much a component industry. And so the DOE program shifted its emphasis towards a systems approach. Some good systems have already been developed; more are needed to achieve wider market impact. We also learned that even the best products fail to acquire the business volume necessary for achieving the kind of impact we all know solar must and can achieve as an energy alternative: a market also must be developed.

Perhaps the most important lesson we learned from all this is that DOE is not and must not be in the traditional government role. We are not, for example, issuing contracts to develop a new missile, or a new helicopter, required to meet the specifications of the government which will also be the sole buyer of the end product. Quite the contrary, since solar energy is to displace conventional fuels in all the major market sectors, we must not only see that products are made to meet various applications, we must also see that there is a real market for these products, that the distribution channels exist for these products to reach this market, and that the industry is capable of maintaining both the products in service and the market itself. We have learned that we are in a new ball game in the energy business just as the country and the world is learning to cope with a new energy situation.

In summary, the lessons learned from past successes and failures include these: (1) It is not enough to have the technology developed. It must be translated into products that meet the cost and performance needs of the market. (2) It is not enough to identify potential applications, they must be developed into viable markets. (3) It takes time for a program to mature and develop momentum and support. (4) Sustained commitment and activity are necessary to get results and payoff. (5) The action is in the private sector and results are achieved at the local level. DOE can help but only if it listens to the program's constituents. (6) It is not enough for the program to be responsive to the needs of the program's constituency. The program must also be organized and presented in such a way that the taxpayers, the Congress, and the decision-makers in the Federal government can all relate to it; accountability must be built into the program, or else the results are not measureable. (7) To achieve significant market impact, there must exist the right management balance. A totally decentralized program is unmanageable. An overcentralized one is ineffective and bureaucratic. The balance is found in the regional approach. The Regional Solar Energy Centers are close to the market on the state and local level, in a position of responsiveness, yet they have sufficient focus to make an impact and they are accountable to DOE, and to the public through their governing board.

It is in response to these lessons that the current market oriented program organization was developed. The program I represent, Solar Applications for Buildings, includes the three solar technologies of greatest relevance to buildings, and all the activities necessary to develop and bring to market products based on these technologies.

The objective of the Solar Applications for Buildings Program is to displace oil and to generate self-sustaining business activity in the private sector. This is the only way to justify the expenditure of program resources.

The key to achieving the objective of the program is the private industry of this country, since it alone can make and market solar products. I am, therefore, committed to strengthen the influence of industry in shaping this program. We need their experience both in Washington and throughout the field organization. I am developing ways to improve the access my office has to this expertise and source of advice.

The role of government is to help and to accelerate in every possible way the natural process by which solar technologies are translated into solar products which will operate successfully in America's buildings. We can and must do all we can to improve communication between the Federal government, the Congress

the solar industry and the public. No one can be successful in a vacuum; not this program, not Congress, not industry. We must learn to communicate our need, our proposed solutions, and our successes as well, far better than we did in the past.

The field network took a lot of work, pain and frustration to build. SERI and the RSEC's are now operational, their programs are maturing and are becoming more and more effective daily. These organizations are essential: together with the DOE field offices, laboratories and other Federal organizations they implement the program. Everything gets done through them. I am committed to support this field network and to improve the communication, mutual trust and collaboration between DOE Headquarters, SERI and the RSEC's. The program, after all, is rather like an organism: it functions best when all its parts are connected and coordinated.

The action is on the local level. The Federal level in Washington is the world of large, integrated numbers, statistics, summarized goals, results and trends. But the reality behind all the Megawatts, Quads and Typical Applications, is the people who are making things happen. These people live in real homes and pay real heating, electric and gas bills. And when one of these people decides to go out to his/her local bank to arrange financing for a solar house, a water heater, attached greenhouse or insulation; and hires a local tradesman to install it for him - that's when this program brings results. And when the solar and conservation products this person bought work well, that's when oil is saved. This is what I mean by "the action is at the local level."

And when a city decides to formulate its own energy program and, having assessed its needs and resources, builds a solar district heating system, passes local ordinances guaranteeing sun-rights, gives tax-breaks to property owners with solar heated homes, or rehabilitates a city block of decaying tenements with energy conserving and solar features: this, too, is what I mean by action at the local level.

The success of this program, the personal success of its people in Washington and elsewhere, and my own personal sense of accomplishment, all depend on the momentum, initiative, resourcefulness and support of this local constituency.

The local level is also the place where many tough policy issues are ultimately resolved. I am sure you often wonder, for example, why are there separate Conservation, Solar and Appropriate Technology programs in DOE. Of the many possible answers to this perfectly legitimate question, consider this one: In Washington we deal with the average household or community, or building, or citizen. We deal with types, trends and kinds-of solutions. We deal with policy. From this vantage point program integration often looks like simply a question of responsibility, authority - or turf. But when your Town Hall is converted into an energy saving building with a solar water heater on its roof, and it is paid for partly by HUD, partly by DOE and supported by both the Conservation and Solar Applications programs, this is when we have real program integration.

This program counts on the Regional Solar Energy Centers and their men and women "on the scene" to keep us focused on the needs of this vast constituency; to help us distribute our resources; to assist in planning and implementing the program; and to provide a local/regional perspective.

Only if we make sure that our decisions are made on the right level can we each be effective. Only then are the people in Washington Headquarters, the DOE field offices, laboratories, SERI and the RSEC's "doing the right thing." It is my responsibility to provide leadership necessary to make sure that we operate in this way. And I intend to provide it.

A reporter once asked the leader of an orchestra what he considered the most important attribute of a good conductor. "You've got to have a good ear," replied the concertmaster without hesitation. Even before the Office of Solar Applications for Buildings was officially formed, we began to formulate a strategy to develop and bring reliable solar products into this market sector. And we began by listening. Many of you participated in this process, either by coming to Washington to the working sessions where the basic content and direction of the strategy was conceptualized; or by reviewing and commenting on the many drafts of the planning and strategy documents and helping to improve them. The final documents are truly the works of the constituency of the Solar Applications for Buildings program. They reflect the thoughts and perspective of people representing as diverse a set of interests as manufacturers and bankers, utility executives and community solar advocates, installers of solar systems and Washington policy makers, state representatives, congressional staffers, marketing experts, and scientists doing research in solar technologies.

The path to reach our goal, when we look at the task from the standpoint of the Active, Passive, Photovoltaic technologies will, of course, be somewhat different. Yet, from the standpoint of the building market - i.e., the collection of brick-mortar-and-wood buildings that form our cities, towns, factories, offices and farms across the U.S. - there is only one strategy, summarized in the following few points:

- Our goal is to become less dependent on fossil fuels. We must act fast. Solar can help.

- The government can help by contributing to a healthy business climate in which the private sector can successfully develop, make and sell appropriate energy conserving and solar products and services. For this it has to understand how industry and the market operate.

- The participation and support of the constituency of the program is essential for success.

- The basic technology for solar heating is ready, but products, services and the distribution system must mature. Solar cooling and photovoltaic systems require further technology development.

- There are many technical solutions to the needs of the marketplace. Priorities for these, are established on the basis of their potential, relative market readiness and the resources required to make them successful.

- Since program resources are limited, the strategy advocates concentration on a limited number of activities with the best potential, on the one hand; and the leveraging of all available resources, on the other.

- To be effective in operating in this way, strong management and coordination is needed at all levels, assuring the most effective utilization of resources and talent available within and outside of the program.

- Planning, Implementation and Evaluation of results go hand in hand, and must be carried out at all levels within the program. The program should focus on real accomplishments and be evaluated in terms of the real energy savings achieved, or the self sustaining business activity generated. This implies that a strong industry, good products and sales, and reliable performance are all necessary for the achievement of energy savings.

- All activities supported by the program must be conducted in adherence to the strategy. If an activity does not fit this strategy, it should be redirected or eliminated.

We in the Office of Solar Applications for Buildings have listened, we will continue to listen, and I assure you, the program will reflect the letter and spirit of the strategy we have developed together. And as we go along, we will continue to improve the strategy together.

* * *

Ladies and Gentlemen: this is my view of the Solar Applications Program for Buildings. I welcome your comments and questions, now or later. In any case, our dialogue did not begin with nor should it end with this presentation, or with this conference. For DOE is not the program. DOE, at its best, only supports what you in the private sector do and accomplish. For this it needs your support, criticism and constructive input; and, yes, occasionally, patience. The alternative is to see DOE at its worst, an isolated bureaucracy that feeds on itself, generates its own world, and invents its own justification.

Let us continue to work together, for the strategy and what it has accomplished so far is only the beginning. On my part, I would be happy to come back and account for program resources in terms of program achievements - that is, oil saved as a result of our work together - next year, the year after and the year after that.

ENERGY STORAGE AND RENEWABLE SYSTEMS

George F. Pezdirtz
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Washington, D.C.

INTRODUCTION

SOCIAL PERSPECTIVE ON ENERGY USE AND ENERGY STORAGE

I am sure that you are well aware of the increasing attention given to the development of alternative energy sources and more efficient energy technologies. The public at large is becoming aware of the interdependence between our life style, our use of energy, and the health of our environment. What we may need to recall is that we are approaching a time of extraordinary change in our social and environmental interactions that suggests we are about to enter a qualitatively different future--different from any other time in history.

Many social observers have given us different ways to think about the shifts we are about to face.* Most natural processes assume the form of an "S" curve when we plot their growth against time. At the inflection point, the population undergoes a transition from accelerated growth to decelerated growth. Presumably, elaborate feedback mechanisms regulate this transition in nature, which preserves an ultimate population size. We are now at a similar transition in our own development--between epoch A and epoch B in Figure 1. Nearing this transition point we are faced with a strong conflict of interests. We feel strong restraining pressures though we continue to expand in many areas. One pressure is the impending gap between energy supply and demand which is clearly one of the most decisive factors in controlling our expanding developments in every phase of our activities. If we can lessen our waste of energy (our entropy) and take a more direct control of its use, we might reach the balance necessary for our very survival.

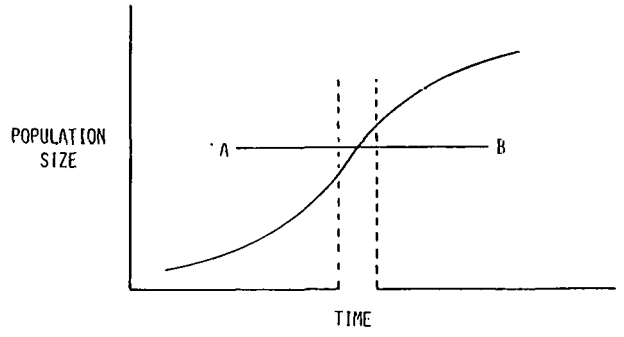


Figure 1. Conflict of Pressures at the Point of Inflection

*See, for example, The Survival of the Wisest, Jonas Salk, Harper and Row, 1973, N.Y.

Before discussing the role of energy storage, let us first examine some of the social factors influencing our energy consumption.

SOCIAL FACTORS INFLUENCING ENERGY CONSUMPTION

Analysis of the development of current and planned energy technologies must account for the inevitable pressures of population size, distribution, attitudes towards consumption, and the increasing output power of machines.

Population

If the growth rate of our world population continues, it will be virtually impossible to deliver energy equitably at the present consumption levels of the developed nations.

Figure 2 illustrates our exponential growth curve; within our own lifetime we will see our total numbers increase from about 2.5 billion to nearly 6 billion people. This means that we will add more people in the next 20 years than were here at the turn of the century! This increase brings with it an amazingly higher competition for limited energy sources.

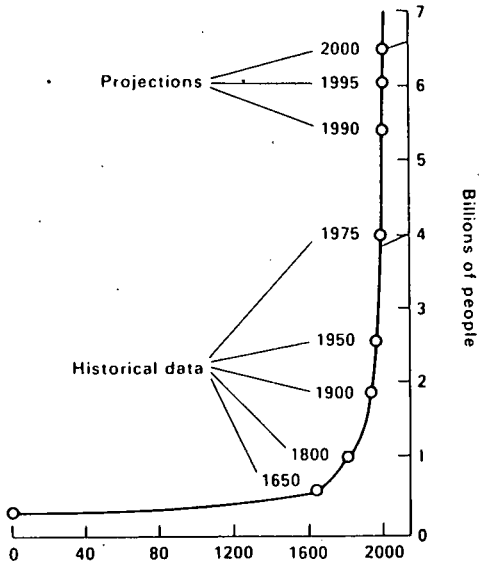


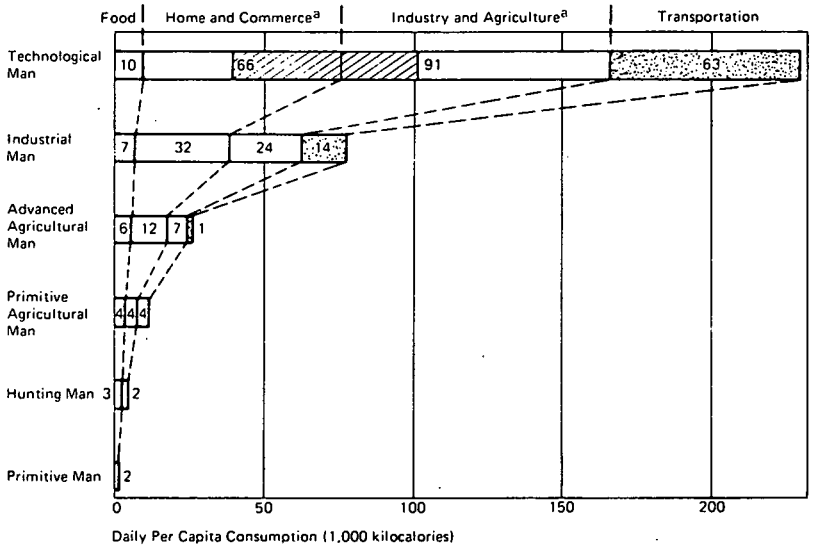
Figure 2. World Population Growth

The global population picture needs to include population distribution to be more complete. An increasing number of people are living alone. The number of people living alone in the United States is now over 25 percent, and as this number increases, our per capita energy demand increases(2).

Today the world urban population is rising at a rate of 6.5% per year. This will result in doubling our urban population in the next eleven years. If we consider that half of all the energy consumed by man in the past 2000 years has been consumed in the last 100 years, we might begin to just barely appreciate the magnitude of the energy deficit we may face.

Attitudes Towards Consumption

Social attitudes also accelerate our traditional energy use patterns. The post-industrial period, sometimes referred to as a period of "hyperconsumerism," requires high mobility and efficient use of time. Over half of the energy consumed in the United States is used to maintain our transportation and communication systems. We use energy to buy time, convenience, and mobility, and as a result, per capita use of energy has increased. Figure 3 illustrates the increase as man has advanced from a primitive to a technically-advanced being, and with this increased use goes increased entropy or waste of resources. The increased use of energy-intensive devices could occur only because of the increase in power output of basic machines (3). As one example, the windmill had a flat energy output for over 250 years until aeronautical principals were incorporated into its design. With the new design the output increased over 100 times. This ancient energy source, wind, is now receiving renewed interest in a number of regions, including Hawaii, which are developing advanced wind machines to decrease their reliance on oil.



[a]The hatched area indicates the portion of energy needs fulfilled by electricity.

Source: Cook, "The Flow of Energy in an Industrial Society"

Figure 3. Daily, Per-Capita Energy Consumption for Six Stages in Human Development

Energy Supply

Taken together, this information suggests that energy demand is increasing not just because of population growth, but largely because of the close interplay between population, life style, the technological explosion of new devices, and new ways of using energy which result in even higher rates of energy consumption. The relationship between per capita energy demand and modern life style, the "quality" of life, is seen by comparing the United States relative to the world, as shown in Figure 4.

A recent analysis (4) of the world energy supply pictures shown in Figure 5, anticipates that OPEC productive capacity will level and that we will have a world energy shortfall in the 1983 to 1985 period. Most of the new industrial practices

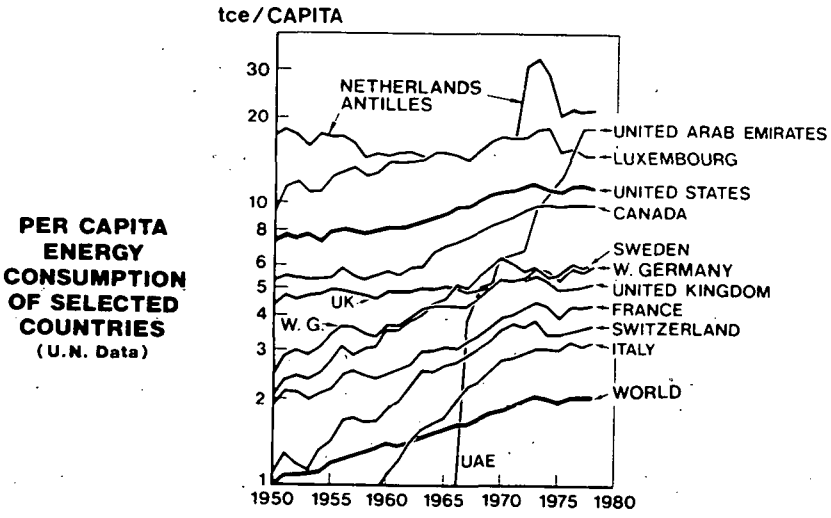


Figure 4. Growth in World Per-Capita Energy Demand

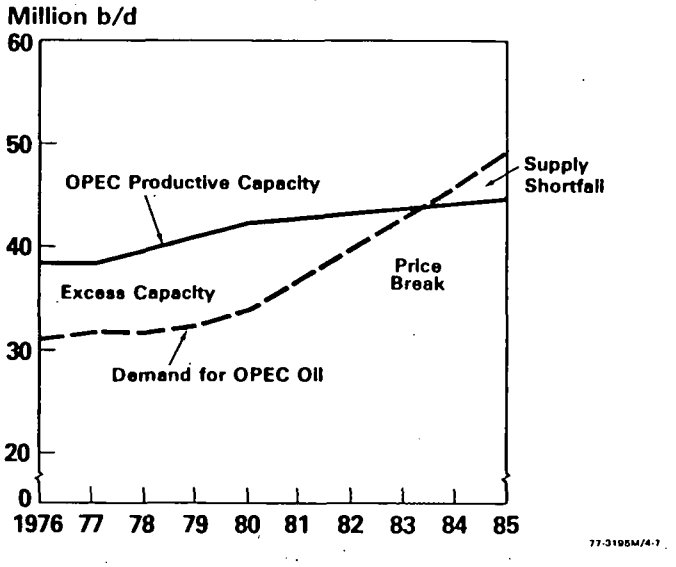


Figure 5. OPEC Oil - The Supply/Demand Gap

and plants needed to decrease our energy use cannot be put in place in that period. Long lead times of 6-12 years are required to build new electric power plants, whether they be hydropower, nuclear, or coal fired. Longer lead times have also been required historically to change our energy use patterns.

Solutions Are Not Easy

There are no easy solutions, no panaceas to achieve the balance necessary for our survival. An old Slovenian proverb tells us that, "Once one loses harmony, it is very difficult to regain it." We need new energy sources and more efficient ways to use all forms of energy. We need to create institutional mechanisms to

obtain these new facilities as early as possible. Most of us don't want to see drastic changes in our lifestyles and adverse changes in our capital investment, but early trend projections clearly point in those directions, and of course in the past 50 years we certainly have seen major changes in individual life style.

One example, already seen is the siginificant change in the mix of automobile sizes. As the price of U.S. gasoline rises we buy smaller cars with improved mileage. Europe and Japan have already shifted to smaller cars. They now manufacture over 25% of the cars we purchase in the U.S. Federal fuel economy standards also mandate further fuel conservation--we have yet to see what kind of job dislocation will be involved.

There is inherent resistance to change, expecially when the elements of time and convenience are involved or when the change is mandated, rather than evolutionary. Figure 6 indicates that while we may be driving more fuel-efficient cars, we continue to drive over the 55 mph speed limit (6) drastically reducing the fuel economy. Technological advances and federally-mandated conservation measures alone will not solve our energy problems. These must be accompanied by extensive educational measures, promoting a thorough understanding of the socio-economic characteristics and the patterns of change which affect energy use, if we are to change lifetime habits. Regulation is also no panacea for changing people's habits!

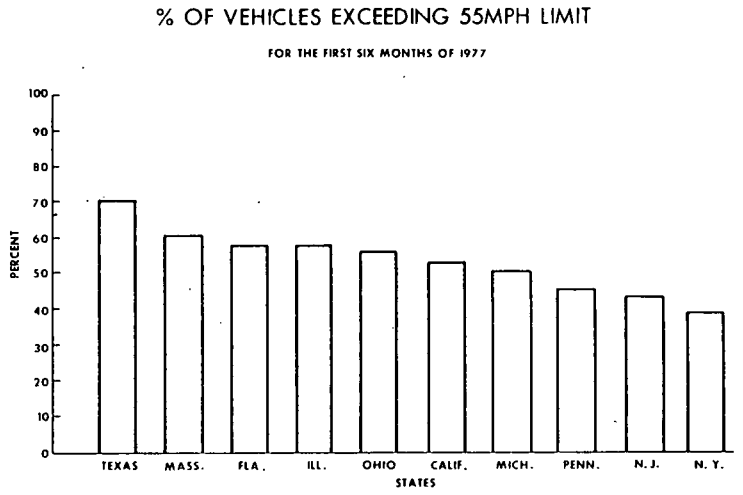


Figure 6. Vehicles Exceeding the 55 MPH Limit.

The Role of Energy Storage

Harmony is a way of nature, and storage helps us to achieve a level of harmony between supply and demand, albeit at some small cost in economics or energy efficiency. Energy storage is one strategy for building the bridge between energy demand and energy supply. It is not a new concept. Sunlight is stored by plants in photosynthesis; the earth has stored energy for over three billion years as gas, oil, and coal.

Energy storage bridges the gap in three ways. First, it increases the efficiency of existing power systems by allowing them to generate electricity continuously at large baseload capacities. Secondly, energy storage enables a broader use of renewable sources. The power output from wind, solar thermal, photovoltaic, and ocean thermal sources is not continuous, but storage will allow

these intermittent sources to match fluctuating demands. Thirdly, energy storage reduces the petroleum-based fuel used for transportation. By enabling a broader use of electric vehicles, storage significantly cuts the amount of Arab oil used in our cars.

The Role of Energy Storage in Hawaii

For Hawaii and other dependent "island" situations, energy storage has an important role in bringing renewable and alternative energy sources closer to the practical stage. Alternative sources which are particularly attractive to Hawaii are solar-thermal energy, ocean-thermal energy conversion (OTEC), and wind energy. In June of this year, a 200 kW experimental windmill was formally dedicated on Kahuku Hills (7). This installation does not currently employ energy storage, operating instead in the fuel-saver mode rather than as firm generating capacity. Energy storage could be installed at some future date; but in the meantime, the study of such small systems under field operating conditions can help us understand the boundary conditions and interfaces necessary to develop models for larger systems.

For electrical generation, Hawaii is almost singularly dependent on petroleum, both for baseload and peaking capacity. Out of a total generating capacity of 1336 MWe; 80 percent is oil-fired steam turbine, 11.7 percent is gas turbine, 5.7 percent is diesel, and 2.6 percent is biomass-fired steam turbine (purchased firm capacity from sugar processors who burn bagasse - sugar milling waste.) Energy storage concepts for peak load management which are attractive for mainland applications would serve no useful purpose on your islands. All that would be accomplished would be the shifting of load from oil-fired gas turbines to oil-fired steam turbines, with no displacement of petroleum. Energy storage could enable the broader use of biomass or waste-fired generating capacity, however. It could also enable solar repowering of existing steam turbine facilities.

Energy storage could also enable a broader use of electric vehicles in Hawaii. Considering the similarities between the range and speed requirements of personal and commercial vehicles in your island transportation system and the target range and speed capabilities of electric vehicles, this transportation form appears particularly suitable for the islands. Electric vehicles would reduce the oil requirements of the islands and, when the electric utilities increased their use of biomass, solar, or other renewable energy sources, then it would achieve a net reduction in island petroleum imports. An additional benefit of the electric vehicle would be reduced pollution levels in urban areas, which will help preserve Hawaii's natural beauty.

With this as a background, let us examine the U.S. Energy Storage Program.

DOE ENERGY STORAGE PROGRAM

INTRODUCTION

The DOE Office of Advanced Conservation Technologies is developing a broad spectrum of energy storage technologies under the direction of National Energy Plan II. At the same time the Office is exploring new applications for existing energy storage technologies.

The DOE Energy Storage Program has three primary goals:

- to encourage the use of coal, nuclear, and renewable sources as substitutes for petroleum and natural gas,
- to synchronize the intermittent sources, such as solar and wind, with the demand patterns for power and heat, and
- to promote energy conservation by increasing efficiency in automobiles, in residential use, and in power generation.

Our timetable for energy storage commercialization is shown in Figure 7.

Energy Storage Systems
Commercial Technology Timetable

Subactivity	1980-1984	1985-1990	After 1990
Batteries and Electrochemical Systems	•Near-term Electric Cars •Dispersed Utility Load Leveling	•Advanced Electric Cars •Advanced Batteries for Load Leveling •Improved Electrochemical Processes •Solar Electric Storage	•New Electrochemical Processes •*Advanced Storage for* Solar Electric
Chemical and Thermal Systems	•H_2 for Chemical Feedstock •*Solar Seasonal Heating* and Cooling •Retrofit Industrial Heat Storage	•H_2 Supplementation of Natural Gas •Chemical Heat Pumps with Storage •Thermal Storage for Load Leveling	•H_2 and Thermochemical Storage for Solar •H_2 for Vehicles
Mechanical and Magnetic Systems	•Utility Storage (UPH/CAES) •Flywheel Regenerative Braking	•Mechanical Storage for Solar Wind	•Advanced CAES •SMES for Utility Load Leveling

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Figure 7. Commercial Energy Storage Technology Timetable

CLASSIFICATION OF STORAGE TECHNOLOGIES

Energy storage technologies may be classified in a variety of ways. One method which I use is to define them by their application as either "Stationary" or "Mobile."

Stationary energy storage technologies operate at fixed locations to satisfy the system needs of electric utilities and the heating, cooling, and convenience needs of individual customers. Electric utilities can use stationary storage to assist in load management, accumulating baseload energy during off-peak periods for use in satisfying peak energy demands. Individuals can use stationary storage to accumulate less-expensive (off-peak) energy or intermittent renewable energies (solar, wind, etc.) for use in heating, cooling, or convenience applications.

The stationary technologies can be further divided into three subcategories depending on the size and application of the technology. As shown by Figure 8, these subcategories are central, intermediate, and dispersed.

Central storage technologies have large capacities, e.g., above 200 MW, and are sited at or near central power plants. These technologies include compressed air, underground hydroelectric pumped storage, and superconducting magnetic energy storage. They are being developed for integration with large- scale utility systems which have a major nuclear or coal-fired component in the baseload generating capacity. Central storage technologies are intended as a means of

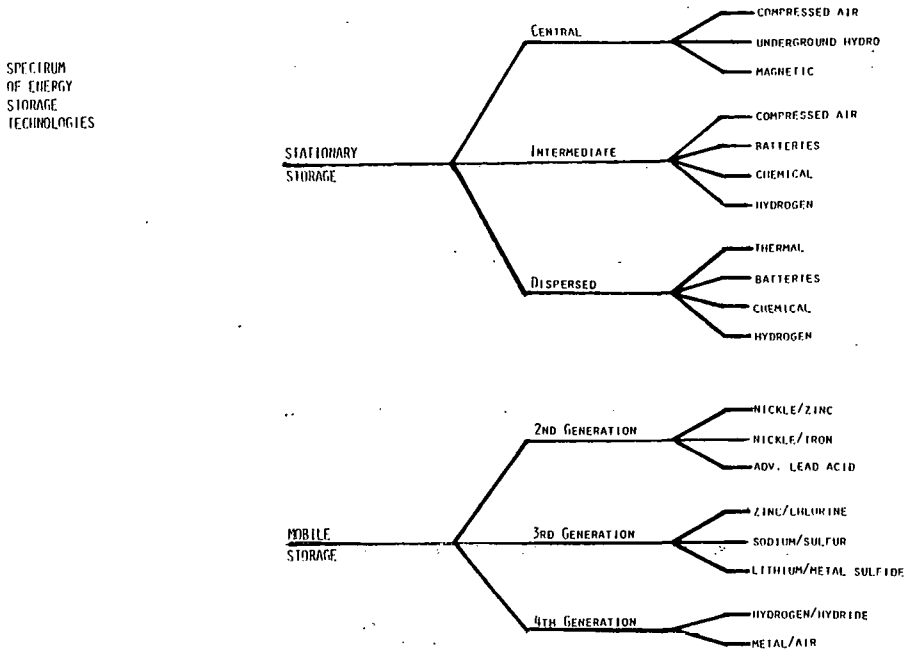


Figure 8. Spectrum of Energy Storage Technologies

adding new flexibility to mainland-type utility systems by meeting peak-power demands and improving system reliability. As such, they are not of immediate interest to the renewable energy technologies or to the needs of your islands.

Intermediate storage technologies are typically intended for utility power substations or power generating systems of 100 megawatts or less. These technologies include batteries, flywheels, chemical systems, and thermal energy storage. Intermediate energy storage technologies will be applied to solar-thermal generating systems, solar repowering of fossil-fired power plants, ocean-thermal (OTEC) systems, wind-energy systems, and quite possibly biomass-fired systems. As such, they are relevant to the needs of your islands' energy systems.

Dispersed storage technologies are generally small in capacity, and are employed at the point of energy consumption. These technologies include thermal storage, batteries, chemical heat pumps, and hydrogen storage. The dispersed technologies are directed at user-owned applications, including solar-thermal HVAC systems, and customer-side-of-the-meter electric load management systems. Like the intermediate-scale systems, the dispersed technologies have direct applications to renewable energy systems and those systems which could reduce your islands' dependence on imported petroleum.

I mentioned three ways in which stationary energy storage will be useful. Use of renewable sources will be aided by intermediate and dispersed storage technologies. For more efficient use of our transportation energy, we must look to mobile storage technologies.

Mobile storage technologies are essentially modular and are used in a variety of transportation applications, from personal vehicles to delivery vans and buses. These technologies include families of battery systems in different stages of development: first, second, third, and fourth generation technologies. First generation technologies are either in full commercial development or are expected to reach that state in the next few years. Second generation technologies are

those which could be in commercial production by the mid to late 1980's; they include the nickel/zinc, nickel/iron, and advanced lead/acid batteries. Third generation technologies include the zinc/chlorine, sodium/ sulfur, and lithium/metal sulfide batteries and may be commercially available in large quantities by the end of the next decade. Fourth generation technologies include hydrogen (H_2 and metal hydrides) as a fuel and the metal/air battery--here large-scale use is not expected until the 1990's.

We will now look at the stationary and mobile technologies in more detail.

STATIONARY STORAGE TECHNOLOGIES

The different roles for stationary storage technologies can best be understood by briefly discussing some specific needs and applications. We will look first at the central storage technologies.

Central Storage Technologies

Figure 9 shows the typical weekly demand fluctuation of an electric utility network. Without storage, or a means of user-owned load leveling, the mechanical and thermal generation of power must follow the load at any particular time. This leads to inefficient operation, since these facilities operate best at steady-state, near their full capacity. Traditionally the problem has been handled by adding more generating capacity, usually in the form of gas turbines, to the utility network during times of peak demand. This is not the most satisfactory solution as gas turbines rely on scarce petroleum fuels, and are less efficient than the baseload generating plants.

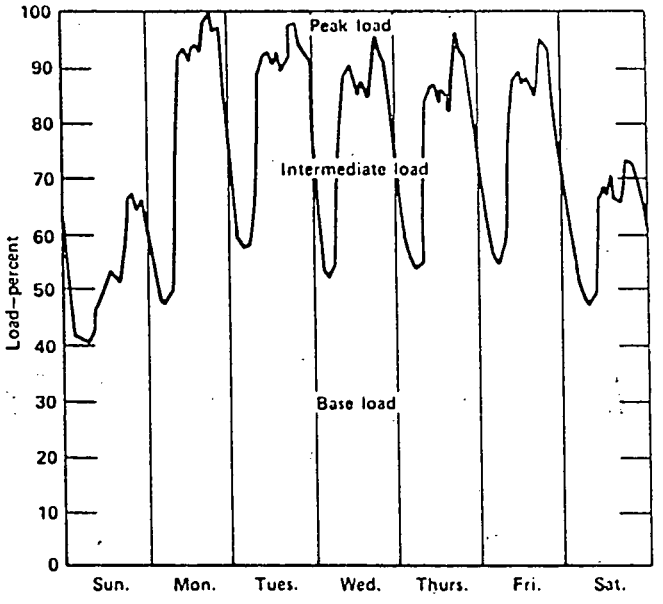


Figure 9. Representative Utility Power Plant Load Curve

A central store of baseload energy could supply peaking power and load-leveling of fluctuations in energy use. The generating mix of the Hawaiian utilities is almost entirely oil-fired, however. The use of energy storage for

load management would not enable fuel shifting, and would probably not realize a net saving of petroleum. The efficienty of energy storage/recovery would most likely consume the difference in heat rate between power from a baseload versus a peaking generator. There is almost certainly no case for central storage technologies in Hawaii, and I will skim over them rather briefly.

Compressed Air Energy Storage (CAES) is directed at near term electric utility load leveling applications. When power generated by baseload plants exceeds the demand (off-peak period), the surplus electricity can be used to compress air which is subsequently stored underground. Compressed air is withdrawn during periods of peak power demand, and fed to a modified gas turbine, eliminating the need for a turbine compressor stage and resulting in an increase in the efficiency of peak-power generation.

Underground Hydroelectric Pumped Storage (UHPS) is being considered as an alternative to above ground pumped hydroelectric storage and gas turbines for load leveling applications. Energy is stored during off-peak hours by pumping water from a low underground reservoir to an upper (surface) reservoir where it is stored until needed. At that time, the water is allowed to fall to the lower reservoir, turning conventional water turbines and electrical generators located underground.

Intermediate Stationary Technologies

Whereas central storage technologies are intended to augment existing utility power-generation systems, the intermediate technologies are directed towards replacement of fossil-fired and nuclear generating capacity with renewable sources such as photovoltaics, solar-thermal and wind energy. Because the renewable sources are anticipated to be operated on a smaller scale than current, very large coal and nuclear baseload facilities, a greater variety of storage technologies are necessary; including batteries, flywheels, chemical energy storage, and high-temperature thermal storage.

Batteries. Advanced storage batteries offer a promising way to assist photovoltaic and wind energy technologies. As shown in Figure 10, excess energy produced during a sunny or windy day would be used to charge a battery for use when the sun is not shining or the air is calm, enabling a steady output from these intermittent energy sources.

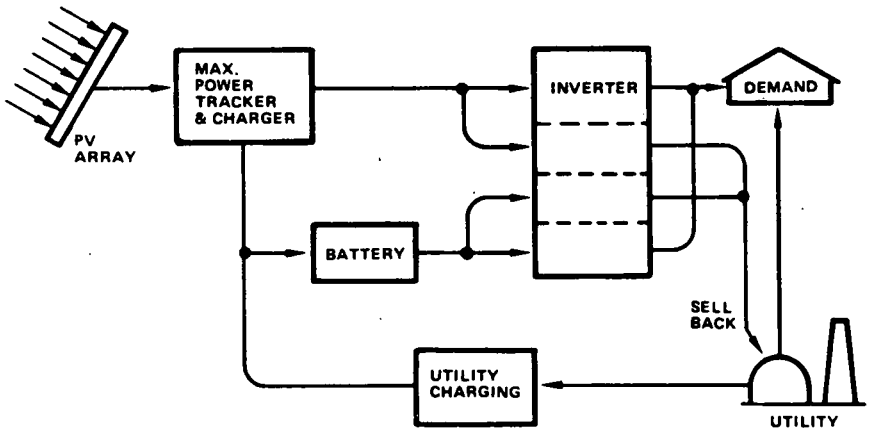


Figure 10. Photovoltaic Storage System

The batteries which are being developed for intermediate-scale applications include zinc/chlorine, zinc/bromine, and sodium/sulfur. Recently, a major development in the zinc/chlorine battery technology was announced by DOE and Gulf & Western Industries. The G&W zinc/chlorine battery is a unique unit because the graphite electrodes contain no active materials, no inter-electride separators, and no catalysts. The absence of these components, combined with the unit's ability to operate at ambient temperature and pressure, results in a significantly increased life and reduced cost. Unlike many other battery systems, the zinc/chlorine battery may be subjected to "deep discharge" without reducing its useful life. Such advanced battery systems will integrate with utility load-management concepts as well as the previously-mentioned renewable energy systems.

The battery development program will involve testing of large-scale prototype battery systems under charge-discharge conditions which simulate the load-management, photovoltaic, or wind-energy system of interest. Two test facilities which will satisfy this need, known as BEST and SBEED, are under construction. The Battery Energy Storage Test (BEST) Facility will test the response of large battery packs under actual utility operating conditions. The performance and cost data from the BEST Facility will enable both battery developers and utility companies to make informed decisions concerning further battery development, application, and system costs. It will also provide specific performance information about power conversion equipment required to convert from AC to DC and vice versa under actual use conditions. Lead/acid and zinc/chlorine batteries are scheduled to be the first systems under test (1981). The largest battery module at the BEST Facilities will operate at about 1000 watts. The Storage Battery Electric Energy Demonstration (SBEED) will be used to demonstrate the use of batteries under actual load leveling operations on a utility grid. The facility's storage capacity will range between 30 and 100 megawatt-hours, with the discharge rate ranging between 10 and 20 megawatts. This plant is scheduled to be operational in the time period of 1984-1986.

Flywheels. A second storage technology for assisting solar photovoltaics and wind energy involves mechanical energy storage in a flywheel. Storage of kinetic energy in a high-speed flywheel with relatively low first-equipment cost has been shown to be feasible. The energy storage capacity of the flywheel depends primarily on the mechanical properties of the materials from which it is fabricated, as they determine the flywheel's maximum speed of rotation and safety characteristics. The energy storage capability is also influenced by the flywheel rotor geometry and assembly. The Department of Energy's development of flywheel storage includes the identification of suitable materials and configurations for the flywheels, the demonstration of large-scale manufacture of high-performance rotors, the reduction of losses incurred when transforming kinetic energy to electric energy, and the ability to maintain competitive system cost.

Chemical Energy Storage. Energy may be stored as chemical energy through electrolysis of water using off peak power or from renewable sources such as low-lead hydroelectric plants (Figure 11) or Ocean Thermal Energy Conversion (OTEC). The hydrogen can be stored in the form of metal hydrides or in large underground caverns for later use as a chemical, as a heating fuel, or in fuel cells to produce electricity directly (see Figure 12). The goal of the Chemical/Hydrogen Energy Storage Subprogram is to develop a technology that will economically substitute hydrogen produced from water for hydrogen produced from oil and natural gas. We are presently developing hydrogen electrolyzers which increase the energy efficiency from 45% to 90% by using solid polymer electrolyzers. We are trying to reduce the overall system cost to a level competitive with the expected price of natural gas in the late 1980s. We expect to reach a capital cost goal of

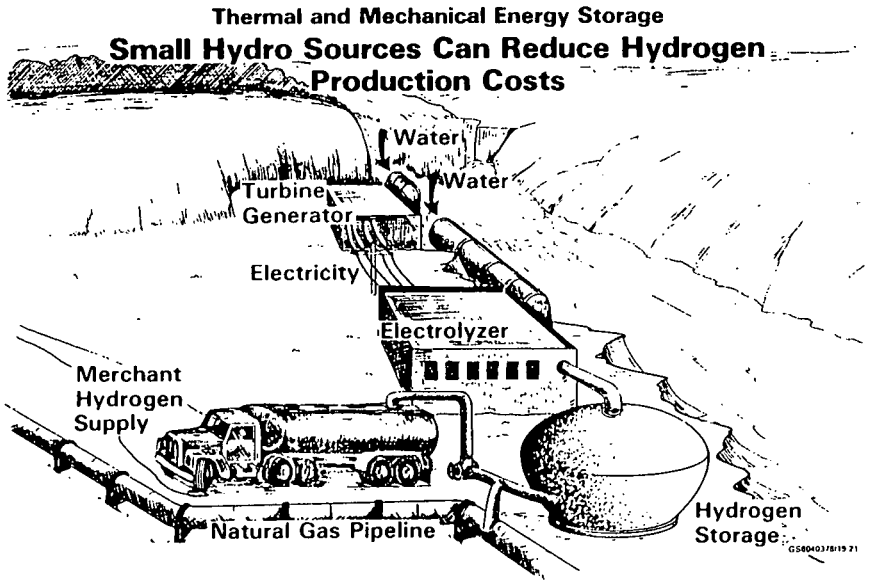


Figure 11. Hydrogen Production From Low-Head Hydroelectric Resources

- CHEMICAL FEEDSTOCK
  - IN 1973, THE PRODUCTION OF H_2 IN THE U.S. CONSUMED 1.3 QUADS OF ENERGY.
  - IN 1973, THE DISTRIBUTION OF HYDROGEN BY USAGE WAS
    - 47% PETROLEUM REFINING
    - 36% AMMONIA SYNTHESIS
    - 10% METHANOL SYNTHESIS
    - 7% MISCELLANEOUS USES
- NATURAL GAS SUPPLEMENTATION
- SPECIAL-PURPOSE FUELS
  (ELECTRIC-UTILITY PEAKING; SPECIAL-PURPOSE VEHICLES; SPACE VEHICLES)

Figure 12. Near and Mid-Term Applications for Hydrogen

$200 per kilowatt by 1984. If successful, we anticipate a longer term system for producing hydrogen from water at a cost of $6/million Btu. At this price hydrogen might be used as a natural gas supplement by the year 2000 (see Figure 13).

High Temperature Thermal Storage will support implementation of solar electric power and allow its penetration into a larger portion of the utility market. The major project areas in the DOE program for High Temperature Thermal Storage program include hourly (buffering) and daily storage using sensible heat and latent heat, and long-duration storage using thermochemical reaction heat.

In the development of latent heat storage systems prior to FY 1980, contracts were awarded for laboratory studies and development of specific latent heat storage

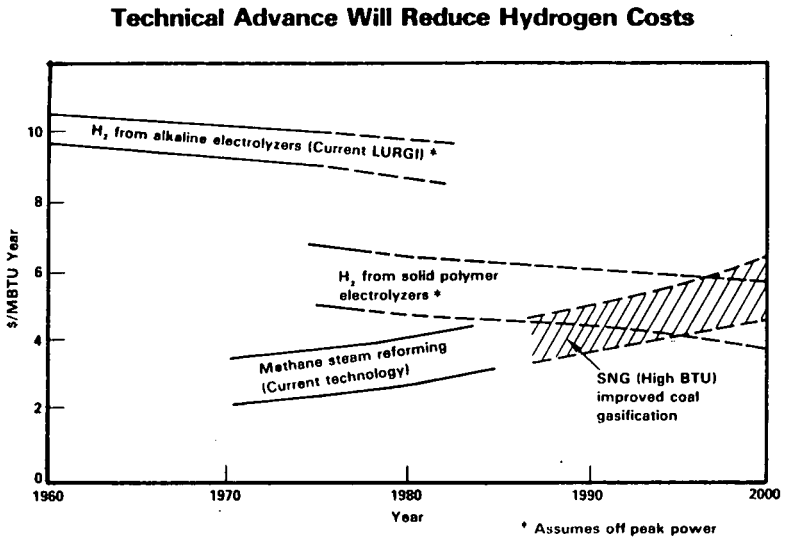


Figure 13. Cost of Gaseous Fuels

technologies selected for availability. Particular emphasis is now being placed on the development of active heat exchange concepts for phase-change storage to be used with advanced solar receivers. A primary program goal is to develop thermal storage components for solar and conventional power generation with a capital cost of $5/kWht and a service life of 30 years by FY 1983.

High temperature thermal energy can also be stored or transported by means of reversible chemical reactions. In this process two chemicals are reacted at high temperature (900°C) to form new products which store the thermal energy in their chemical bonds. These new reactants can be transported over hundreds of miles at ambient temperatures to a place requiring process heat. When the new reactants are passed over appropriate catalysts, the reverse reaction takes place and high-grade heat (600°C) is released. The EVA-ADAM concept shown in Figure 14 is under development in Germany as a means of transporting energy from high-temperature nuclear reactors. While an emphasis is placed on storage for Rankine power cycles, storage for alternative power cycles is also being developed.

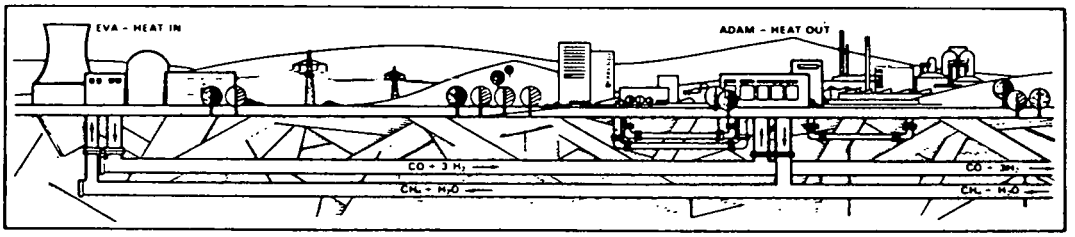


Figure 14. The EVA/ADAM Concept for a Thermochemical Pipeline Employing Reforming Methanation

Dispersed Storage Technologies

Dispersed storage is used when energy must be stored at the point of consumption. The technologies within this subcategory are thermal storage, batteries, and hydrogen storage. The underlying principles of these technologies have been discussed previously and remain constant for dispersed uses.

Thermal Storage. The discussion of thermal storage technologies requires elaboration as there is a wide variety of end uses for dispersed thermal technologies; including utility load leveling, industrial waste heat recovery, solar thermal energy systems, and daily or seasonal storage for building heating and cooling.

For customer-side-of-the-meter load leveling, off-peak electricity is converted to thermal energy, stored at the customer's location, and used to meet thermal demands during peak periods. This use of thermal energy storage reduces peak utility electric demand. Customer storage is applicable whenever electricity is used to provide a thermal service such as space conditioning or water heating. Commercial, energy-storing space heating units are used in Europe and are under evaluation in the United States. Off-peak water heating systems will be similar to existing units, except for an increase in storage capacity to meet an entire day's supply. In both cases, the incentive for customer acceptance is a rate structure which makes off-peak electric power an attractive option.

Waste industrial process heat can be stored and used later either for space heating, process heat, or for generating electricity. One potential system for the steel industry, a cogeneration system to reduce peak electrical load requirements, is illustrated in Figure 15. The system would use the hot exhaust gas from electric arc furnaces, storing the heat in a packaged bed of slag, and then use this as the heat source to drive a steam turbine. Such a system could be cycled once or twice each day. The annual energy savings from using storage in energy-intensive industries such as, food processing and pulp and paper, are expected to average 250,000 BOE per plant. With expansion and technology transfer to other energy intensive industries (iron, steel, and cement) the energy savings could be as great as 105 million BOE annually by the year 2000.

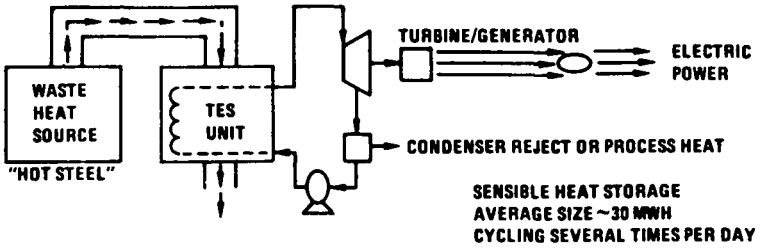


Figure 15. Energy Storage for Heat Recovery in the Primary Metal Industry

Thermal energy storage for solar-thermal power involves the transfer of large quantities of high-temperature heat, typically 500° to 750°C (930° to 1380°F). The technologies involved are in the developmental stage, and include storage as

sensible heat in hot oil, latent heat in molten salts, and thermochemical heat in reversible chemical reactions. To provide baseload utility generating capacity, solar-thermal facilities must include thermal energy storage. High-temperature thermal energy is accumulated during fair weather and daylight hours. It is then recovered to generate power at night or during short periods of inclement weather. Therefore, cost-effective storage is needed for periods as short as a few minutes or as long as a day.

When applied to building heating and cooling, seasonal storage enables efficient use of alternative energy from such diverse sources as solar-thermal collectors, industrial waste streams, utility and industrial cogeneration facilities, and winter-chilled air. The primary focus of the DOE seasonal storage effort is developing technology for aquifer storage and conducting large-scale demonstrations. The technical and economic feasibility of storing waste energy in confined underground bodies of water will be evaluated at sites in Alaska, New York and Minnesota beginning this month. Three preliminary contracts have been signed and final contract negotiations are under way for the two-year design phase of the Department of Energy's Auqifer Thermal Energy Storage Program (ATES). The three projects now funded are:

(1) Bethel, Alaska: This system will incorporate a low-temperature (about 200 degrees F) heat-injection system for this fishing village of 4,000 people located on the Bering Sea. Waste heat from Bethel's diesel-powered electric plant will be used. Initial plans call for using the stored energy to heat Kowokwim Community Hospital, a 50-bed facility to be opened in September 1980. If the heat storing capacity is great enough, it may be possible to heat the community college, the high school and a housing division.

(2) University of Minnesota: A high-temperature aquifer storage system will heat a portion of the school's St. Paul campus. Heating has been a major expense because of the size of the campus and the severe winter climate. The aquifer water will be heated to about 300 degrees to enable greater energy storage and retrieval. It will also increase heating efficiency and permit heating of buildings some distance from the aquifer. The demonstration project at the University will be compatible with a major modification of the power generation and heating system.

(3) Stony Brook: This campus of the State University of New York was considered an ideal spot for an aquifer storage project since much of the necessary equipment is already in place. The study calls for modifying the school's cooling tower to chill aquifer water in winter to about 44 degrees F. During warm-weather months, the stored energy would be used to cool five graduate school buildings, which account for about 60 percent of the school's air-conditioning load.

Daily or short-term thermal energy storage involves accumulating heat (or cold) during part of the day or during several days, followed by using the accumulated energy over a similar time period. One technology being investigated for this application is the chemical heat pump. Chemical heat pump storage for solar heating and cooling systems offers the potential of compact storage as well as a heating and cooling operation in one unit. A chemical heat pump (Figure 16) is a device that operates as a result of the spontaneous movement of vapor between two different chemical reservoirs. Chemical heat pumps make possible lower overall cost and greater efficiency than separate solar heating, cooling, and storage units. Laboratory testing is underway on several chemical heat pump storage

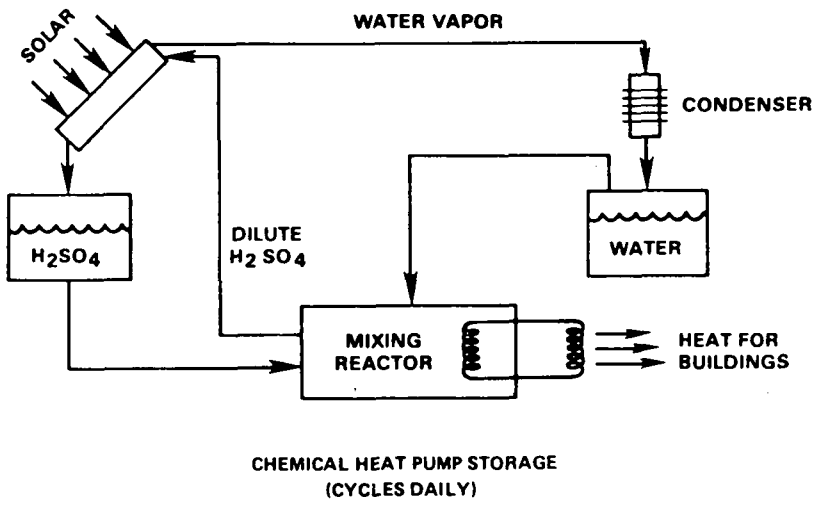


Figure 16. Chemical Heat Pump Storage System

concepts. One or two of these will be selected for prototype development, performance testing, and economic evaluation. Chemical heat pump units could save about 33 BOE per residence annually. Assuming 3,500,000 units are operational by 2000, the estimated potential energy savings are 115 million BOE annually (about 0.65 Quad). Energy savings from these advanced storage technologies will accrue mainly by their accelerating the market penetration of solar heating and cooling.

It is now apparent that there are many concepts for central, intermediate, and dispersed stationary energy storage applications. Intermediate and dispersed technologies will be the most useful for enabling a broader use of renewable sources, and for this reason will be the most useful to oil-dependent regions such as Hawaii. Precisely which technology is used for any particular need will depend on the nature of the need and the suitability of the specific technology for fulfilling it.

MOBILE ENERGY STORAGE

I have already noted that a considerable amount of the energy is used by our transportation systems. To improve the efficiency of these systems, we need storage technologies specialized for mobile uses. Energy storage in electric or hybrid automobiles, light trucks, and urban buses will allow greater penetration of these transportation modes in areas, such as Hawaii, where they can be used on a large scale. Figure 17 summarizes the design objectives of one such electric vehicle.

The DOE program for battery mobile storage development consists of first, second, third, and fourth generation technologies.

Minimum Passenger Capacity	4 Adults
Maximum Curb Weight	2566 lb
Initial Cost (1975 $)	$5000
Minimum Urban Range	85 miles
Minimum Top Speed	70 mph
Minimum Acceleration (25 to 55 mph)	10 sec
Minimum Acceleration (0 to 30 mph)	6 sec
Minimum Ambient Temperature Range	- 20° F to + 125°F
Battery Type	Lead-Acid

Figure 17. Design Objectives for Garett Electric Vehicle

1st Generation Battery. The speed and range characteristics of conventional (1st generation) batteries are not adequate for passenger cars, as shown in Figure 18. However, these batteries would have limited use in delivery vans if the overall lifecycle cost could be reduced by a factor of 2 to 3. The U.S. Department of Energy is continuing work on lead acid batteries, as well as on the development of a hybrid battery-flywheel vehicle. The goals of this program include:

- Flywheel regenerative braking systems for use in ground transportation to reduce energy consumption 30 percent in delivery and service vehicles which start and stop frequently.
- Batteries for transportation having an energy density of 140 watt-hours per kilogram, a peak power capability of 200 watts per kilogram, and a cost less than $40 per kilowatt-hour.

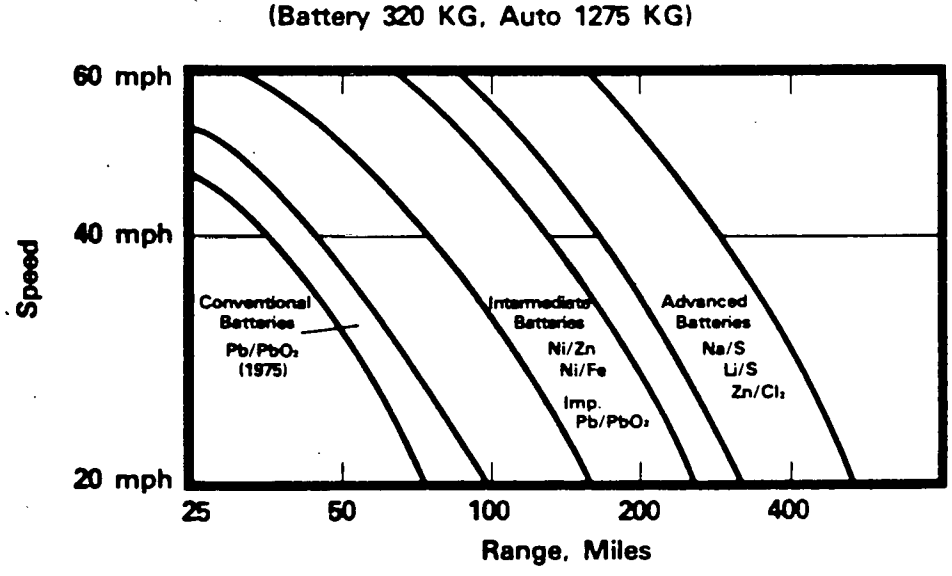


Figure 18. Applicability of Several Battery Types to Electric Vehicle Operation

2nd Generation Battery development is aimed at improving those batteries still in the laboratory stage, bringing them to a limited production level within the next several years. They are being prepared for U.S. demonstration electric vehicles of the mid to late 1980's. The three batteries being developed are nickel/zinc, nickel/iron and advanced lead/acid. We expect the energy density and the power of these batteries to be from 2 to 3 times that of current lead/acid batteries.

3rd Generation Battery technology includes lithium/metal sulfide, sodium/sulfur, and zinc/chlorine batteries. Experimental studies are underway on lithium/metal sulfide engineering prototype cells, with work focused on increasing battery life and performance, while reducing costs. Our present lithium/metal sulfide cells have capacities of 200 to 250 watt-hours with a storage density of about 60 to 90 watt-hours per kilogram. Sodium/sulfur batteries have attained energy densities of 100 wh/kg, or 71% of their program goal. Zinc/chlorine batteries currently attain 80 wh/kg, or 73% of their goal.

4th Generation Technologies for mobile applications include metal/air batteries and hydrogen/metal hydride storage. The two metal/air batteries being investigated are the lithium/air and the aluminum/air systems. These batteries have previously exhibited limited power capacities. However, recent work suggests that these limitations may be overcome. For the long range (year 2000), the aluminum/air cells have the potential to afford extensive ranges (up to 400 kilometers). Refueling would consist of adding water and removing dry $Al(OH_3)$ powder which could be recycled (see Figure 19). After 1000 kilometers, completely new aluminum plates would replace the depleted ones, and these could also be recycled.

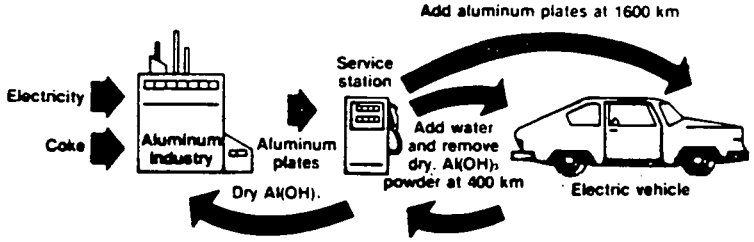


Figure 19. Aluminum-Air Battery Powered Vehicle Refueling Process

The hydrogen/metal hydride stores utilize certain alloys of iron, nickel, and titanium which will form interstitial hydrides when exposed to hydrogen under moderate pressure. Metal hydrides are granulated, packed in tubes, and bundled in a container. When heat is fed through the assembly, hydrogen gas is released and discharged as a fuel for use by an internal combustion engine which powers the vehicle. One application of hydrogen as a mobile storage technology is the hydrogen bus which has been developed by Mercedes-Benz in West Germany. It is projected that, by converting a fleet of 300 urban buses to run on hydrogen, this technology could save a city the size of Stuttgart over one million gallons of petroleum fuel a year.

AFTERWORD

It should be abundantly clear by now that energy storage technologies will have an increasingly significant role in helping us reach our balance for survival.

As we set out to develop practical ways to reach this balance, we must remember and be prepared for the conflict of interests and the dilemmas we will face*:

- We need economic growth. We can't live with the consequences of a no-growth economy. Such an economy fails to provide us with the meaningful work opportunities we need for wholesome individual development.

- Our own continued economic growth will preclude a more equitable distribution of earth's resources, yet our social, political and hence economic system, will eventually depend on how well we achieve equitable distribution throughout the world.

- We need guidance for technological innovation. We can not shun centralized guidance and support of development efforts. Yet our increasing inter-dependence must not threaten our individual liberties.

We have no simple solutions for these dilemmas. But we must find new ways of looking at the problem and new approaches in our attempts to resolve them.

What will the future really look like? As Thomas Hobbes reminded us, in the 17th century the typical life was "poor, nasty, brutish end short." Many historical trends have already pointed to a steady increase in the material quality of human life. But this is the turning point in history at which man becomes either the victim or the master of change.

The stage has been set for a completely new way of dealing with our interdependency as a world community. The many and complex difficulties and the challenges of the 21st century will call into question man's capacity for adaptation. Salk may indeed have chosen the clearest title for our future in his Survival of the Wisest.

ACKNOWLEDGEMENT

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*Willis Harmon - private communication.

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COMPREHENSIVE OVERVIEW PAPER ON ELECTRIC ENERGY SYSTEMS FOR RENEWABLE ENERGY TECHNOLOGIES

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ROLE OF ELECTRIC ENERGY SYSTEMS WITH TRADITIONAL GENERATION

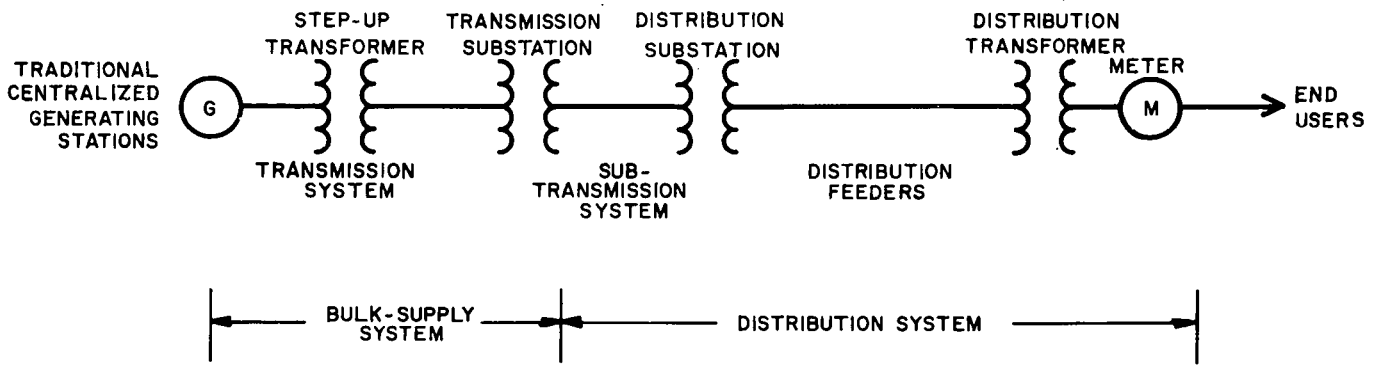
The role of the Electric Energy Systems, Figure 1, is to tie together the traditional centralized generating stations and deliver the electrical energy to the end users. This is generally thought of in two segments:

(a) the bulk power supply system which includes and ties together the various generating stations and delivers the energy through the transmission and subtransmission system---to the

(b) distribution system, which receives from the bulk power supply system and delivers the energy to the many end users.

FIGURE 1

ONE-LINE REPRESENTATION OF TYPICAL ELECTRIC POWER SYSTEM



The traditional generating units are often located remote from loads due to availability of cooling water, fuel transportation, etc. These generating units are dispatched and operated so as to achieve minimum total cost for fuel, system losses, maintenance and cost of operations. The bulk power supply system achieves reliability through multiplicity of generating units, transmission lines and substations. The underlying principal is that with any unit or line out-of-service, even at time of maximum load, the remaining system can still deliver the required energy to the distribution system at the required locations.

This multiplicity approach to achieving total system reliability is not utilized throughout the distribution system as it would be quite expensive in terms of investment and facility utilization. Instead the typical distribution system is basically "radial", using a single supply approach. This is supplemented by quick restoration and repair after faults and outages occur.

FUTURE ROLE OF ELECTRIC ENERGY SYSTEMS WITH DISPERSED STORAGE AND GENERATION (DSG)

The role of Electric Energy Systems changes with the trend from traditional centralized generation changes towards renewable dispersed generation. This reflects the different characteristics of the renewable energy sources:

1. Instead of being operated to match variations in user loads, output is dependent upon some other variable such as: sun, wind, ocean temperature, seasonal availability of biomass, etc.

2. Location is dictated by factors such as wind, ocean thermal, biomass source, fuel by-product of process, agriculture, etc.

3. Dispersed generation will have smaller electrical rated units as compared to traditional generating units.

4. Zero or low incremental fuel cost, and

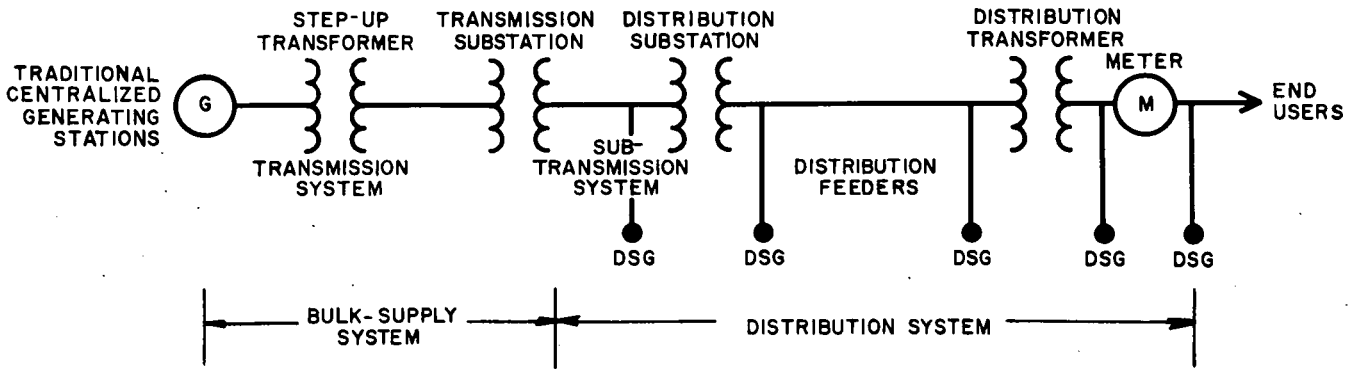
5. Capital intensive.

Because of these differences the new generation sources tend to be dispersed, or can be dispersed without economic penalty. The fuel cost/investment difference tends to encourage user ownership and operating responsibility. Since output cannot be controlled to match user load variations, daily and seasonally, it may be desirable to either store some of the renewable energy until time of higher user demand, or to shift some user demand to more nearly match the availability of the renewable generation sources.

Accordingly, future renewable generating sources tend to be dispersed, and storage installations will become more prevalent. Storage may be at the same site or elsewhere on the power system. The fact that both tend to be dispersed as illustrated by Figure 2, means most will be connected to the

FIGURE 2

ONE-LINE REPRESENTATION
OF FUTURE ELECTRIC POWER SYSTEM
WITH DISPERSED STORAGE & GENERATION



distribution system, others to the distribution substation or subtransmission system. Hence, the future role of the Electric Energy System is expanded to integrate these new dispersed storage and generation installations (DSG) to achieve overall economical, reliable, and safe operation in combination with the traditional centralized generating stations.

Future increase in number of generation and storage installations connected to the distribution system will significantly change the requirements for planning, controlling, protecting and operating both the distribution system and the companion bulk power system. For example, increased control will be required to assure optimum utilization of the dispersed renewable sources and storage installations, in harmony with the centralized traditional generation. The additional control and monitoring will bring with it increased requirements for communication between various parts of the system, including communication between the new dispersed storage and generating installations. Additional cooperation will be required between the power company and users to achieve optimum total performance.

The presence of dispersed generation and storage units will drastically change the present "radial" nature of distribution systems, particularly the primary feeders beyond the substation. Whereas power flow now is always from the substation toward the users, future DSG's will result in power flowing in the opposite direction, at least part of the time. This will require improved control and protection systems to assure reliability of supply to all users, to minimize the effect of power system faults and disturbances upon the many dispersed generating/storage installations. To achieve safe operation of both the new DSG's and the distribution system will require changes in operational and protective practices.

On the other hand, there are some inherent advantages in having DSG's connected to the distribution system:

1. Reduced system losses since some of the generation is now closer to the users.

2. Improved reliability of service since some generation is now on the user side of some causes of interruptions.

3. Reduced requirements for bulk power and subtransmission systems since some of the generation is now closer to the users.

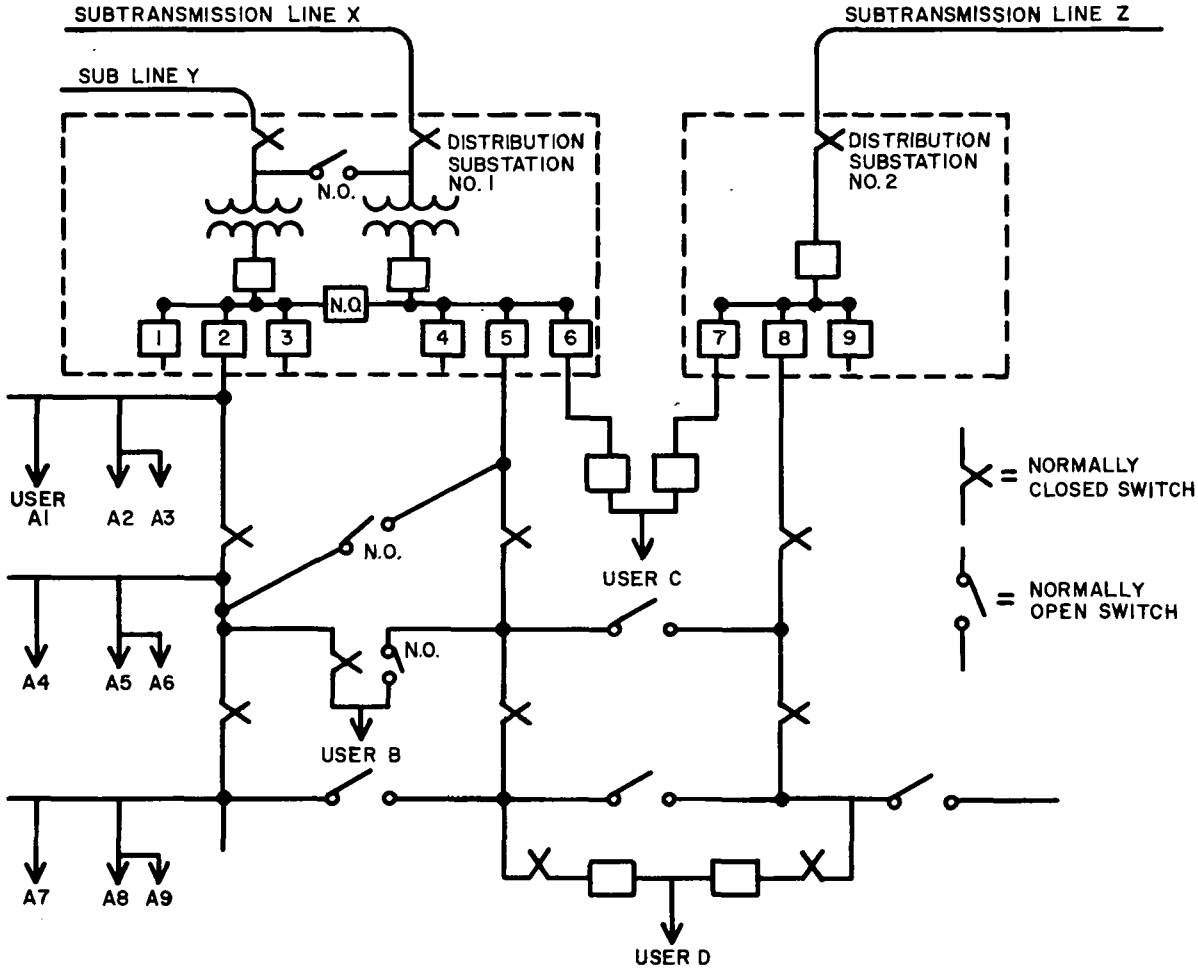
Accordingly, the integrating role of the Electric Energy System will be significantly increased, as renewable dispersed storage/generation installations move through the demonstration phase to increasing penetration in future power systems.

Numerically, how many future DSG installations may we expect? Forecasts range from 4% to 20% of the US electrical energy in the year 2000. For illustration, if we use 10% with an average size of 500 to 2000KW, this corresponds to 40,000 to 150,000 DSG units operating in the year 2000. Hence, the number of installations will become significant.

EFFECT OF DSG ON DISTRIBUTION SYSTEMS

To highlight the effect that significant penetration of DSG will have in the future, it is helpful to review the wide variety inherent in distribution systems. This is shown by Figure 3 which illustrates conditions encountered in distribution substations and primary feeders to serve various types of users, both today without, and in the future with DSG.

FIGURE 3
ONE LINE DIAGRAM
OF TYPICAL DISTRIBUTION FEEDERS



Two substations are shown in Figure 3, substation #1 with two transformers and two independent subtransmission circuits, substation #2 with only a single subtransmission line and a single transformer bank. The primary feeders from these substations are typically radial, with five of these feeders illustrated. On the left are small users A1, A2 -- A9 typical of residential users. They are supplied by radial feeder #2, which is typically overhead. When a fault occurs on this primary feeder, breaker # 2 opens to de-energize and isolate the fault. When there are overhead line sections, the breaker is usually reclosed automatically to try to restore service promptly after de-energizing a temporary flash over -- say of an insulator caused by lighting stroke. However, if the fault is of a more permanent nature, such as a pole knocked down by a vehicle, the feeder breaker will again trip and ultimately lock open, thus interrupting service to all connected users. Trouble crew(s) are dispatched to use manually operated sectionalizing switches to split feeder #2 into three sections, and

determine which section has the fault. Previously open tie switches are used to restore service to the two unfaulted sections. This reduces the outage to users connected to only one feeder section. Temporarily some of the sections may be connected to other feeders. When the fault has been repaired the service is restored to all feeder sections and all sections are reconnected in their normal configuration. During the time that repairs are being made User A1, A2, and A3, etc., have no alternate supply and they are interrupted for the time required to restore service to their feeder section. User B, which might be typical of a smaller industrial or commercial building is normally fed by feeder #2, but can be transferred to an alternative feeder #5. This transfer may be manual, automatic, or remotely controlled.

The majority of users are supplied radially as described. When a disturbance occurs automatic reclosing attempts to restore service to all. When successful, users experience an interruption of only a fraction of a second or at most a few seconds. When automatic reclosing is not successful then users served by the unfaulted feeder sections are restored manually, typically in 1 to 4 hours, while those connected to the faulted section are interruputed until repairs can be made, typically 4 to 12 hours.

Where improved customer reliability is desired beyond that associated with radial service, then "multiplicity" can also be utilized in the distribution system. This is illustrated by user C and user D, where two different feeders are paralleled at the user premises. Service is maintained, through appropriate protection and control, even when one of the feeders is de-energized and the user load is not interrupted even temporarily. Only a modest number of users have this type of service. Typical would be commercial buildings, shopping centers and moderate to larger industrial plants with critical processes.

An underlying premise in the design and operation of the distribution system shown by Figure 3 is that the energy source is the bulk power system and delivered through the three subtransmission lines. The basic operation of the distribution system is radial and seldom are generating sources included at the substations or user facilities. Modest exceptions do exist, such as peaking combustion turbines connected at a distribution substation or co-generation operating at user locations such as C or D. Where these generating installations are present they include appropriate modifications to the "radial" operating and protection principles to achieve protection of the generating equipment and safety to personnel operating the distribution system. Accordingly, DSG can be connected at users C or D with only modest changes to present practices.

It requires greater change from present day practice to connect DSG at users A--A9 or at user B since these now have only radial feed. For faults on radial systems the present practice is to open the feeder breaker, thus de-energizing the primary feeder and all associated users, to then automatically and rapidly re-energize to attempt to restore service after transient faults. The presence of DSG on such feeders means that the fault path will no longer be inherently de-energized by tripping the substation feeder breaker. To completely de-energize a feeder also requires isolating each DSG and/or sectionalizing at intermediate points on the feeder. To reclose the feeder breaker before all DSG's are disconnected will not only be unsuccessful, since the feeder was not de-energized, but the reclosing may harm the DSG equipment. After a feeder has been de-energized and returned to service, each DSG must now be resynchronized and reconnected to the system. Therefore, to accommodate DSG on radial feeders requires fundamental rethinking of distribution system automation and will increase communication requirements.

OVERVIEW OF DOE PROGRAMS - ELECTRIC ENERGY SYSTEMS

The US Department of Energy (DOE) Office of Electric Energy Systems, (EES) reporting to DOE Assistant Secretary For RESOURCE APPLICATIONS is responsible for a broad, long range program for integrating new technologies into the nation's electric energy network, and to provide options for increased power transfer capability over existing and future transmission rights-of-way. Being the only program office which specifically takes the systems approach to the electric energy network, EES fulfills an important role for tying together the energy source and end-use electric energy technologies.

The broad overall objective of the EES Program is to help insure that the nation's electric energy system is capable of meeting future demands reliably, with the lowest practicable energy losses, with maximum energy conservation, and in accordance with environmental and National Energy Policy principles and policies. To this end, the EES Program focuses on Research Development and Demonstration (RD&D) designed to produce benefits in support of the national energy priorities of improvement in the efficiency of the electrical energy systems (increased capacity utilization, decreased capital requirements, increased reliability, etc.); fuel shifting from oil and gas to more abundant nonrenewable resources in the near term and to renewable resources in the long-term; energy conservation; and environmental enhancement.

From a technical perspective, there are several benefits from the EES Program. Improved total system reliability (relative to the reliabilities of system components) is a principal anticipated benefit and reduced time for the introduction of new technologies is another. The program also provides independent, objective evaluation of the impacts of various new technological alternatives.

Program Strategy

EES Program strategy consists of assessing the near and long term research needs of electric energy systems, keeping informed on the type and amount of research being performed by others, and sponsoring or conducting the RD&D necessary for implementation of specific technologies on a regional or national basis.

While there are some distinct differences, the equipment manufacturers, the Electric Power Research Institute (EPRI), the utilities, and DOE have overlapping involvements in the broad task of electric energy systems development. Detailed discussions of program plans are carried out with EPRI, utilities, and electric utility task forces to minimize the amount of overlap and bridge the gap between research needs and research and development efforts.

EES involvement is focused on expediting the development of higher risk, long-term payback technologies and development of technologies which have a significant potential for enhancing the implementation of National Energy Policy. Thus, EES support of RD&D ranges from totally funding efforts in longer term payback areas such as superconducting transmission, to sharing the costs of reducing the technological impediments to nearer term system components.

National laboratories have been given the responsibility for managing major efforts in load management, distribution automation and control, and super-conducting transmission development. Utility systems are also engaged in managing a number of projects. These include the operation of the Battery Energy Storage Test Facility (BEST) and the 4.8MW fuel cell power plant, as well as other important but relatively less expensive projects such as field tests of alternative communications system, automatic generation control, etc.

Project Areas

The total EES program is organized and carried out through nine Project Areas:

1. Load Management and Distribution Automation
2. Systems Control and Development
3. Dispersed Generation & Storage Integration
4. High Voltage Alternating Current (HVAC)
5. High Voltage Direct Current (HVDC)
6. Underground Transmission
7. Electric Field Effects
8. Energy Storage Applications
9. Generation Applications

Each will be summarized briefly. Then those that are directly applicable will be related to this conference on Renewable Energy Technologies and the specific papers on electric energy systems scheduled for presentation this afternoon and tomorrow.

1. LOAD MANAGEMENT AND DISTRIBUTION AUTOMATION

The Load Management program is to obtain working knowledge of the feasibility, applicability and economic benefit of load management and distribution automation and control.

Load Management

The objective of the program is to develop basic foundations for the management of loads to improve efficiency, to optimize fuel use (including shifting fuel dependency from limited to more abundant energy resources), reduce reserve requirements for generation and transmission capacity, to minimize operating costs and to enhance the reliability of the overall system. These goals, based on the ability of a given utility to communicate with and control specific loads, allow the utility to modify the actual or apparent system load patterns. This involves establishing communication and control systems which interacts with customer loads, customer energy storage, utility energy storage, dispersed new generation technology, and expanded interconnection of power systems. Performance and economics are being established through demonstrations prior to widespread implementation.

Distribution Automation and Control

This program has an overall objective to assure that distribution automation and control capability is available and its performance and economics understood in sufficient time to support demonstrations in load management, reliability enhancement, and DSG applications.

2. SYSTEMS CONTROL AND DEVELOPMENT

The Systems Control and Development program is to conduct major research to develop theory and methodologies for the control and development of large scale electric power systems. Two major thrusts comprise this program:

Complex Systems Control

This Program seeks an integrated treatment of the normal, alert, emergency and restorative mode of power systems operation. The ultimate goal is the development of a control system which adapts itself to alternate modes of operation automatically.

Large Scale System Development

This program seeks improvements in planning techniques, control system structuring, systems analysis, forecasting and evaluation.

3. DISPERSED GENERATION AND STORAGE INTEGRATION

The principal objective of this program is to develop the framework for effective integration of new technologies, including solar, into the nation's electric energy network. In concert with the National Energy Act, a corollary objective is to provide the methodologies and control technologies to maintain system reliability and effectiveness as the new source technologies are integrated into the power grid. This includes development of system planning and control methods required for the integration of dispersed generation, storage, and load management technologies into the existing and future electric energy network. Power conditioning and control equipment for connecting new dispersed generating sources to the AC power system, including DC to AC converters and constant frequency AC converters for variable speed wind and OTEC generators. Also to test for grid-related interactions with concepts such as load management, central storage systems and widespread use of intermittent generation technologies. System information on new source technologies will be transferred to public and private utilities to encourage and facilitate early penetration into the electric system.

4. HIGH VOLTAGE ALTERNATING CURRENT (HVAC)

High capacity electric bulk power delivery facilities are required for increasing power density, coupled with the need for transmitting large blocks of power from large central generating plants remote from population centers. These facilities must also integrate (reliable interconnect under all conditions) traditional generating facilities, future concentrated locations of renewable type generation, and pool-to-pool interconnections. Research projects in this area emphasize more efficient use of transmission lines and associated equipment to find a solution to the severe limitations on transmission corridors and the transfer of large blocks of power over broad areas of the nation. Included are proto-type 1200KV compressed gas insulated equipment (GISE).

5. HIGH VOLTAGE DIRECT CURRENT (HVDC)

HVDC additions, either as an overlay to existing AC systems, or in new arrangements to link load centers, separate islands or off-shore power plants offer considerable promise for more economic transmission of bulk power, enhanced systems stability, reduced environmental effects and increased power delivery reliablity. This activity concentrates on the development of a better understanding of the benefits and limitations to the wider application of DC transmission, hardware development of HVDC circuit breaker, $\pm$600KV cable and improved terminal conversion equipment.

6. UNDERGROUND TRANSMISSION

High capacity and high voltage underground power transmission systems will receive increased attention as the use of overhead lines becomes less acceptable, particularly in urban and suburban areas because of aesthetic, social, or local policy reasons. EES programs are focused on the development of 1200KV compressed-gas insulated cable system, AC superconducting transmission, improved materials and measurement techniques plus submarine cables for OTEC plants. The unique requirements for OTEC plants are for "bottom" cables for depths four to five times deeper than present experience plus "riser" cables from these depths to "floating" plants subject to continual tide and wind motion.

7. ELECTRIC FIELD EFFECTS

The Federal government began a comprehensive program on electric field effects in 1975, through the DOE office of Electric Energy Systems, the Division of Biological and Environmental Research and the Bonneville Power Administration, primarily to ascertain whether there were barriers, other than technological, to using even higher transmission voltages in the Nation's electric power network. This research program, structured to keep pace with the expanded technology of overhead transmission needs, is identifing and characterizing health effects that may be induced by electric and/or magnetic fields associated with high-voltage overhead transmission lines. The multi-faceted program has four essential elements: measurement of electric fields, basic biological studies, applied biological and behavior studies, and acoustic annoyance studies.

8. ENERGY STORAGE APPLICATIONS

Just as no single form of generation satisfies all generation needs, no single storage device will satisfy all storage requirements. The Dispersed Storage program will provide a range of storage options to make available optimum storage and generation mix for various system conditions. Development projects are sponsored on the application of several advanced battery technologies, compressed air and underground pumped hydro storage. Also two battery test and demonstration facilities -- Battery Energy Storage Test Facility (BEST) and Storage Battery Electric Energy Demonstration (SBEED) are underway. BEST will evaluate prototype load leveling batteries, and SBEED will help quantify system benefits of battery storage and provide important operating experience on an actual power system.

9. GENERATION APPLICATIONS

The ability of the typical mix of traditional base load and peak load generators to meet fluctuating demand can be enhanced by new generation concepts whose primary objective is to increase generating plant efficiency by 10 to 20% and to shift the fuel consumption away from oil and gas presently consumed by diesel and turbine peak load generation. The principal project under development is the 4.8MW fuel cell power plant. This project is in the transition phase from RD&D to commercialization.

SPECIFIC RELEVANCE OF EES PROGRAMS TO RENEWABLE ENERGY TECHNOLOGIES

The DOE-EES programs support the planning, implementation and operation of renewable energy technology. They provide a foundation for system analysis and integration with the existing power system, definition of the new equipment and demonstration of how it is connected and operated compatibly with the present power system.

- DSG SYSTEM ANALYSIS AND INTEGRATION

  Each of the available technologies for new renewable energy generation and for storage must be carefully planned and evaluated to achieve maximum performance of the new equipment itself and optimum benefits in combination with the existing power system. Many existing procedures for system analysis and evaluation will not accommodate the new renewable energy technologies. Therefore, present DOE programs emphasize studies, new and improved techniques for analysis, simulation and planning. Examples will be described by the first paper tomorrow morning: "System Impact of Dispersed Sources".

- NEW, RENEWABLE & DISPERSED GENERATION SOURCES

Let's review some of the unique features of the new renewable generation sources.

-GEOTHERMAL

From the viewpoint of the electric energy system, these plants are similar to conventional plants and represent no new or unique integration problems.

-OTEC

The ocean thermal plants will have output ratings comparable to smaller conventional plants of today. Accordingly, they will be connected to the subtransmission or bulk power supply system. They will be unique in that they will be located off-shore and require cables for connection to the power system. Also because of their off-shore location it will be important that the equipment be compact and operate reliably in the salt air environment. These are the specific subjects of three papers scheduled during this conference tomorrow afternoon:

Riser Cables
Bottom Cables
Compact Terminal Equipment

The operation and dispatching of OTEC plants, in combination with the existing centralized generation, will essentially be an extension of present practice. Generally, the OTEC facilities should be "base loaded" because of their zero "equivalent fuel cost" and low incremental operating cost. Accordingly, they should be operated at the maximum time available to displace more expensive nonrenewable fuels. They may be variable speed/frequency and the energy output variation will be dependent upon water temperature differentials which will not coincide with times of maximum user demand. The performance, control and dispatching of these plants are expected to be extensions of techniques used today for fossil or nuclear "base load" units and for "run of the river" hydro units. A specific paper on this subject is scheduled for tomorrow morning: OTEC Integration.

-FUEL CELLS

The basic module size being developed under DOE sponsorship is 4.8MW and will be initially demonstrated in the metropolitan New York area. Future operating installations will consist of various output ratings depending upon the fuel availability and other site conditions. Installations may consist of multiples of the 4.8MW module size, or maybe smaller. Installations of 2MW and higher are most suitable for connecting to distribution substation buses. Accordingly, integration with the existing power systems is somewhat similar to gas turbine and diesel peaking units presently installed and connected at substations. However, economics, control, protection and dispatching of fuel cell installations will be quite different. Smaller sizes ranging from 100KW to a few hundred KW may be at user locations, particularly co-generation.

The paper this afternoon, "Fuel Cells and Biomass", will cover fuel sources, fuel conversion and fuel cell applications from multi-megawatt size electrical generation to less than 100KW for transportation applications.

-WIND

These units range from one to a few thousand kilowatts. Prototypes are now in operation and more are scheduled and planned. Because of their small to modest

size, individual units will be connected to the distribution system, either at user locations or at locations on the primary feeders. When several, or a large "farm" of wind installations are at one physical location, the combined output maybe connected directly to a distribution substation bus by dedicated circuit(s). The system analysis, system integration, control, protection and operation of these installations is quite different from today's practice due to the variable output capability and speed which is a function of wind velocity. Analysis and simulation programs have been developed and are being further improved. Dynamic electro-mechanical oscillations may occur between one wind machine and the power system and between wind machines. There are two basic approaches for connecting these to the power system (1) to generate at the power system frequency, requiring the wind machine to include control of speed and power output to be compatible to the power system. (2) Let the wind machine operate at variable speed, frequency and voltage but connect this output through electronic power condition equipment which converts it to the 60 hertz power system frequency and voltages. These various approaches will be covered in a paper to be presented tomorrow morning entitled "Wind Integration".

-SOLAR

Solar installations, a number of which are operating and planned, tend to fall into three significantly different categories:

- Thermal - When there is no electrical output the effect on the electric power system is indirect, e.g. water heating, space heating or process heating that might otherwise be user loads on the power system.

- Thermal Electric - A collector system or central receiver provides input to a thermodynamic cycle which drives a turbine generator. These may be new installations or may be to repower an existing fossil fuel installation. Integration and operation on the power system is similar to OTEC and to other traditional peaking generation installations, e.g. combustion turbine or diesel.

- Photovoltaic - Produces DC electrical output which can be utilized independent of, or connected in parallel with the electric power system. Electronic power conditioning equipment is required to interconnect to the power system and to supply conventional 60 hertz utilization devices. Inherently, the electrical output is a function of the sun, which varies widely and independent of user electric demand. The system analysis, integration, control, protection and operation is very different from traditional experience. These installations, while modular, tend to be small to modest in output rating, ranging from a fraction of a KW to a few hundred KW. Accordingly, they will usually be connected to the distribution system, often at user premises. At this conference there are numerous papers in the technical sessions dedicated to solar technology. Within the Electric Energy System program there are no specific solar papers. However, the paper tomorrow morning on "System Impact of Dispersed Sources" is applicable to integrated and locating solar installations within the power system.

  Dispersed solar installations inherently change the present radial nature of the distribution system. Considerable effort is required and underway to determine optimum design, control, protection, operation, and dispatching of large numbers of such installations. These will inherently increase the need for communications to and from a large number of locations on the distribution system. The increased amount of data to be analyzed plus the increased number of decisions required by power company dispatching personnel may well accelerate automation of distribution system monitoring, control, and protection.

- STORAGE

-THERMAL VS. ELECTRIC STORAGE

The majority of the renewable sources of the future have output which varies independently of, and is not directly controllable to match user requirements. Accordingly, these intermittent sources must either be operated in conjunction with conventional generation to meet the varying user loads, or storage is required to utilize the output when available and return it to the system at times of higher user demand. For some solar applications storage will be thermal, and will indirectly effect the user demand on the power system. Other storage will be electrical, to be charged during times of available generation and returned through the power system to meet periods of maximum customer demands when renewable generating sources are unavailable or at less than capacity. Some power companies now use pumped hydro-storage. Several additional types of electrical storage are in the prototype stage, including batteries, compressed air, and underground pumped hydro.

-DEDICATED VS. SYSTEM STORAGE

The first reaction of some is that storage should be dedicated to, and located with, the dispersed generating sources. However, economies of scale and operation usually favor locating the storage elsewhere on the power system and operating it independently of the dispersed generating installations for the benefit of the utility system as a whole. This is the subject of the next paper on the program this afternoon: "Systems vs. Dedicated Storage".

-BEST FACILITY AND SBEED

Two battery programs are underway with DOE and EPRI sponsorship. Both of these are for system storage, and are described in the third paper this afternoon: "Load Leveling Battery Systems--Testing and Demonstrations".

- EQUIPMENT/POWER SYSTEM INTERFACE

-COMPACT EQUIPMENT FOR OTEC

OTEC installations require more compact terminal equipment than used for land based substation and generating plant installations. The compaction is necessary because of the high cost of space on the off shore installations plus the fact that the salt atmosphere introduces requirements more severe than for most land based installations. This requirement for compact equipment is an industry trend above and beyond OTEC installations. The compact equipment requirement for EHV and UHV installations is being driven by the cost of land, the desire to reduce site construction time and cost, improved reliability and improved aesthetics. DOE is sponsoring development of compact equipment both for UHV and OTEC application. This is the subject of a paper for tomorrow afternoon's session: "Compact Terminal Equipment".

-SUBMARINE CABLES FOR OTEC

The floating location of OTEC installations requires that they be cable connected to the "on shore" power system via cables at depths 4 to 5 times greater than present experience. DOE programs are responding to this problem, and described by two papers tomorrow afternoon: "Riser Cables" and "Bottom Cables".

-POWER CONDITIONING

Inherently, the electric power available from three of the new technologies is at DC rather than AC, specifically solar, fuel cells and battery storage. So electronic power conditioning equipment is required to interconnect between the power system 60 hertz constant frequency and the new types of installations. In addition, wind and OTEC generated energy may be at varying frequency. This is the subject of a paper this afternoon: "Power Conditioning".

-HVDC vs. HVAC

There are conditions where DC transmission has advantages over AC. Some examples include a large OTEC more than a few miles offshore, or the under water interconnection between islands. Even for specific interconnections within a bulk power system the controllability of the DC will improve the performance of the overall power system. These subjects are covered by several DOE sponsored programs and are the subject of two papers tomorrow afternoon: "Interconnecting AC and DC Systems" and "Hawaii Specific Problems -- Deepwater DC Cable Transmission".

-COMMUNICATIONS, CONTROL & PROTECTION

The increasing penetration of dispersed generation and storage installations will require very significant increases in communications, protection, and control of these new installations to achieve optimum operation of these in concert with existing power systems and traditional centralized generating stations. While some changes will be required by installations such as geothermal, OTEC and fuel cells which may be connected to the bulk power or subtransmission portion of existing power systems, the new requirements become even more significant when the installations are dispersed out on the distribution system itself, including user locations.

- Load Management and Conservation

  When these new installations operate together with load management systems, the optimum deployment of the new generation and storage installations becomes much more complicated than today's experience in optimizing traditional generating systems for minimum fuel costs. Particularly significant are the economics of locating and operating the dispersed generation and storage installations on the distribution system, thus, minimizing the requirements that these place on the bulk power and transmission systems--a subject that is discussed by the first paper tomorrow morning: "System Impact of Dispersed Sources".

  With rapidly increasing energy costs, it is important that user loads and utilization be efficient and optimized with the supply system. These are the subject of numerous DOE programs. The planning and implementation of new renewable energy sources needs to be done in harmony with a load management and conservation program to achieve optimum total results.

- Distribution Automation

  Today's distribution systems are operated with a high degree of human intervention and step-by-step decisions. For example, when a primary feeder recloses automatically but unsuccessfully and locks open, it is up to a dispatcher to send out trouble crew(s) and to supervise step-by-step, via radio, as they manually sectionalize that feeder, (Fig. 3) determine which is

the faulted section, restore service to the unfaulted sections, repair and manually return to service the faulted section. These operations may require several hours for one feeder. Imagine the number of decisions required of the distribution area dispatcher when a lighting or wind storm moves through the service area and involves outages of a large number of feeders. Often the operators are just not able to keep up and their delays in arriving at appropriate and safe switching procedures adds to the time required to restore service to all users. This is resulting in increasing interest in automating more of the distribution system decisions and operations. This can be achieved using digital techniques for logic, for memory and for data banks. By utilizing information where it originates, rather than transmitting more and more information to a dispatcher, the majority of routine decisions can be made and implemented automatically. Then the dispatcher can be informed, on a lower priority basis, of the new conditions that exist, for example, after the non-faulted feeder sections have been automatically restored to service. He can take additional appropriate action, on a lower priority basis, to locate faults, repair and restore normal system conditions. He can be relieved of many of the routine but high priority decisions required during storm conditions. This approach to distribution automation is in the prototype stage and demonstrated on single substation installations. The growing presence of DSG on distribution systems will further increase the decisions and actions required by dispatchers, both under normal conditions to achieve optimum performance, and under abnormal conditions to protect the equipment, to restore service rapidly and safely. Accordingly, the growing future usage of DSG is projected to accelerate the automation of distribution system monitoring, control and protection.

- Communications

The trends toward load management, distribution automation and DSG installations on distribution systems, all very significantly increase the requirement for communications. This includes communication between DSG installations, with the distribution area operators and with the bulk power system operators. There are a number of alternatives for this increased communication and data transfer, including signals superimposed by distribution power-line carrier on the power system itself, space radio and dedicated voice grade "telephone" type circuits. DOE and EPRI are sponsoring demonstrations of these types of communications and several utilities have been actively investigating the use of load management and distribution automation control systems that use various types of communication media. This subject will be covered by the second paper tomorrow: "Communication Requirements".

WHY IS RD&D IN SYSTEMS ESSENTIAL FOR FUTURE RENEWABLE RESOURCE UTILIZATION?

It is easy to demonstrate feasibility of any one of the new renewable generation or storage installations alone. It is more difficult to achieve optimum operation of that single installation reliably and safely in combination with the existing power system. To achieve optimum operation requires system analysis in advance of each type of installation so that appropriate adjustments be made in the development, planning, design, installation and operation of that installation. While this is significant for only one installation, it becomes mind boggling when it is visualized that power systems of

the future will have increasing percentage penetration of renewable DSG installations. The ultimate to be reached in some locales is that all new installations will be of the new renewable and dispersed type. Hawaii may well achieve this before other states.

The acceptance rate of renewable energy technologies and DSG will be determined by reliability and total system economics. These are measures of mutual interest of the power companies and the users. In order to plan and achieve optimum performance of these multiple dispersed installations, it is extremely important that RD&D in systems analysis, planning, and prototype demonstrations be done well in advance. This is desirable so that the results can be thoroughly understood, reflected in system planning, development programs and early installations to realize in practice the theoretically achievable advantages as more and more of the system consists of these new types.

This is the reason that DOE-EES programs and the papers at this conference, place so much emphasis on RD&D of the newly emerging technologies.

OVERVIEW OF GEOTHERMAL HYDROTHERMAL DEVELOPMENT

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Introduction

Geothermal energy is the natural heat contained in the earth. In many areas the structure of the earth below the surface provides a ready means of extracting the heat, and three types of usable resources exist: hydrothermal, geopressured and hot dry rock.

Hydrothermal resources occur where porous or fractured rock is filled with water or steam in a region of unusually high temperature. Geopressured resources occur in deep sedimentary formations, such as in the Texas and Louisiana Gulf Coast, and contain dissolved methane that may prove to be economically recoverable. Hot dry rock resources often occur in large volume near underground heat anomalies where the porosity or fracturing is insufficient to contain enough water to form an exploitable hydrothermal resource, and heat extraction by introducing water into man-made fractures appears to be the only practicable approach for development.

Extraction of heat from hot dry rock and extraction of methane, together with thermal and hydraulic energy, from geopressured resources are under active investigation in the U.S. but are not yet ready for commercial development. The contribution from each of these resources in the U.S. could far exceed that from hydrothermal resources, but the uncertainties are large. The present paper will concentrate on hydrothermal resources and not discuss the other resource types any further.

Hot springs were used through the ages for therapeutic baths, by the Romans to heat buildings, and in the Middle Ages for district heating schemes. Natural geothermal steam was first used to produce electricity in Italy in 1904 and in 1958 New Zealand first used steam produced from hot water, by allowing it to boil at the surface in flash tanks, to provide commercial electricity. Thirteen countries throughout the world now have a total of 2105 MWe of geothermal-generated electricity capacity on line (Figure 1) and plans to triple this figure by 1985 include nine additional countries. Significant direct uses in nine countries (Table 1) amount to over 7000 MW (thermal) and the growth of these uses is also expected to increase rapidly.

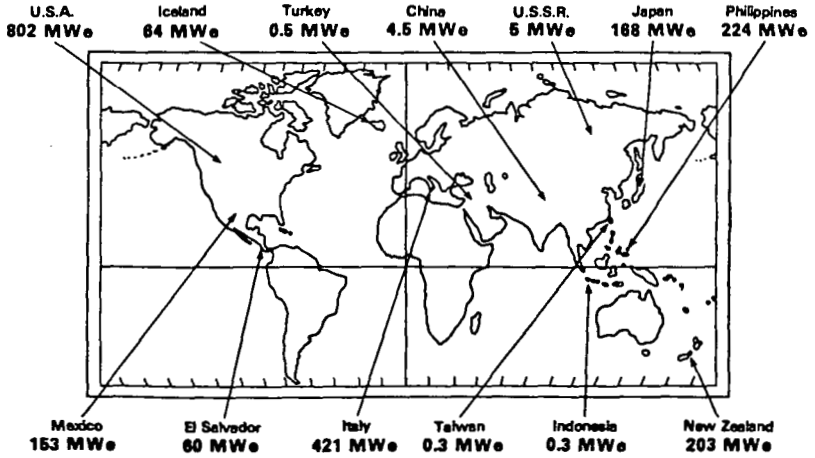


FIGURE 1 Worldwide Distribution of Geothermal Power (Total 2105 Mwe)

The U.S. currently has 802 MWe of electric capacity on line and projections [1,2,3,4] range from 2,000 to 3,000 MWe in 1985 and 7,000 to 25,000 MWe for the year 2000. The numbers depend on various assumptions and will clearly be influenced strongly by

TABLE 1 Countries with Significant Direct Use of Geothermal Energy in 1979 (in Thermal MW)

	SPACE HEATING	AGRICULTURE	INDUSTRY
USSR	120	5100	-
ICELAND	680	40	50
HUNGARY	300	370	-
NEW ZEALAND	50	10	150
USA	75	5	5
ITALY	50	5	20
JAPAN	10	30	5
FRANCE	20	-	-
TAIWAN	-	-	100

both world events and industry and Federal actions. Projections for direct-heat uses are more difficult to make but the Interagency Geothermal Coordinating Council (IGCC) has set goals of 0.1 quads per year by 1985 and 1.0 quad per year by 2000.

The pace of geothermal development has increased significantly in the past two years, and the coming two years will see even more striking developments. Pacific Gas & Electric Company's Units 13, 14, and 15 have added 294 MWe at The Geysers and Units 17 and 18 together with Northern California Power Agency's (NCPA) #1 will soon add 275 MWe more. In the Phillipines the 224.2 MWe that came on line since 1978 will be supplemented by 550 MWe by 1982, and in Cerro Prieto, Mexico, Units 3&4 which added 75 MWe last year will soon be supplemented by Unit 5 at 30 MWe. Two new geothermal fields have been put into operation this year in Imperial Valley at East Mesa and Brawley.

In Hawaii the 3 MWe wellhead generator system at Puna should be ready for operation by next May, and by that time the results of drilling by private industry on the Big Island will be known and the state/county planning team will have prepared plans for rapid geothermal development of the Big Island and evaluated the economic feasibility of direct-heat applications on Oahu and other islands.

Geothermal energy is one of the cleanest, safest, and most economically attractive energy sources available, and its contribution to increasing domestic energy supplies, and to reducing U.S. dependence on oil imports, can be considerable.

The Nature of Hydrothermal Resources

Magma, the hot molten rock below the earth's crust, comes very near to the surface at the edges of the major continental and suboceanic plates. The U.S. Pacific Coast, Alaska and the Aleutian chain form part of a "ring of fire" around the Pacific where there is a great deal of volcanic and seismic activity. Pockets of magma exist near the surface under quiet volcanoes and along major earthquake fault zones. Underground water in highly fractured or permeable rocks becomes heated and circulates by convection, depositing dissolved minerals to form a cap rock which can cause pressure to build up and create underground pools of steam

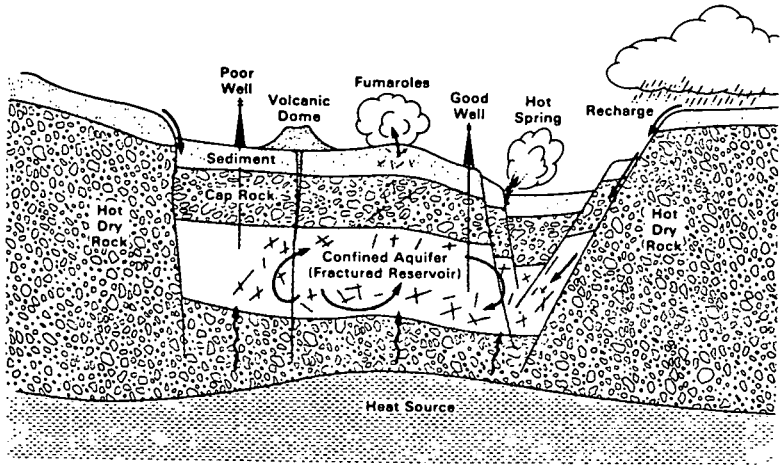


FIGURE 2 Liquid Dominated Hydrothermal System

or hot water. If a path to the surface exists it will create hot springs or geysers as in Figure 2. Such a reservoir is often fed by rainwater or snowmelt flowing through faults that flank the rift valley or the slopes of the caldera formed by the volcano.

Other areas that are well within the boundaries of a major continental plate may have a thinning of the crust that causes a large region to have magma close to the surface, producing high heat flow as in the Snake River Plain. Again any significant body of water contained in permeable rock will become heated and constitute a hydrothermal reservoir.

In addition to magma chambers and regions with high heat flow, a point source of heat sometimes exist where an ore body rich in radiogenic isotopes of uranium, thorium and potassium has intruded and remained hot through radioactive decay. Such radiogenic plutons exist in the Eastern Coastal Plain of the U.S. where they provide moderate heat to overlying hydrothermal aquifers.

U.S. Hydrothermal Resources

High temperature resources, above 150°C, exist in the 14 western states, and low-to-moderate temperature resources occur throughout the U.S. in 38 states. Figure 3 shows the approximate distribution of the U.S. resources, where it should be emphasized that "potential" or "known" geothermal resource areas are speculative until they have been proved by drilling.

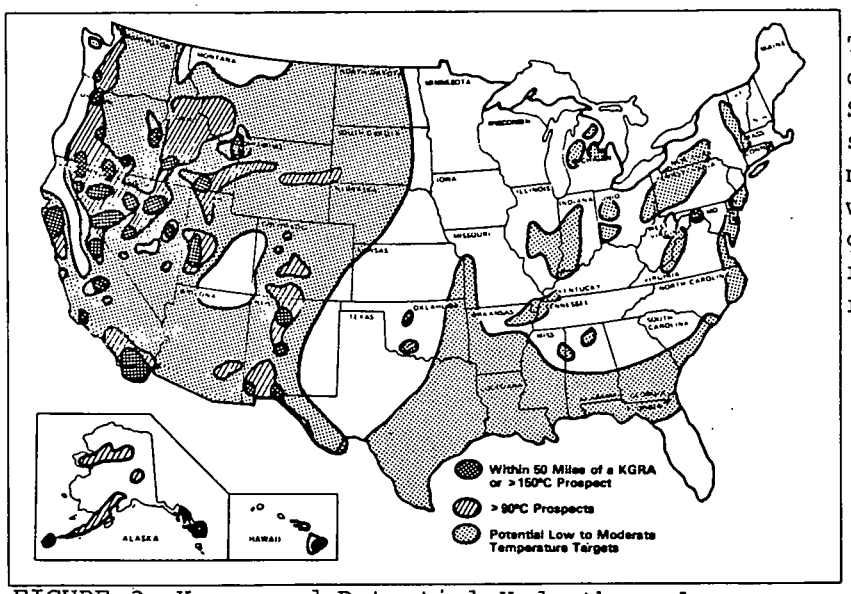


FIGURE 3 Known and Potential Hydrothermal Resources in the United States

The resource assessments conducted by the U.S. Geological Survey (USGS), with help from state agencies for low and moderate temperature resources, were published last year[5] and give an estimated maximum resource base for liquid-dominated reservoirs of 9,000 quads (i.e. quadrillions of Btus) at above 90°C. Using various assumptions the USGS estimates that 2,300 quads are technically recoverable and 350-400 quads are economically available for utilization. For the portion of the resource above 150°C the estimate is 85-140 quads economically available for utilization.

Development of Hydrothermal Resources

a. Electricity Production

The production of electricity from dry steam is relatively straightforward. However the steam contains corrosive and toxic gases which need to be scrubbed out to protect the environment and hydrogen sulphide effluent must be reduced to a very low level by one of several processes. Removing H_2S upstream of the turbines

reduces blade erosion, and the recently developed EIC process for this has been demonstrated at The Geysers.

Dry steam fields are rare, and the more common resource is hot water or two-phase flow at high pressure. At temperatures of 200°-300°C the usual technology is to flash the fluid to produce steam as illustrated in Figure 4, and to inject both the spent brine and the condensate and spent cooling water into the ground. Good reservoir management calls for injecting spent fluids so as to recharge the reservoir and extend its useful life. Where hot water reservoirs provide only moderate temperatures of 150°-220°C there are economic advantages in transferring the heat to a working fluid such as isobutane or isopentane, chosen to extract more of the energy from the brine because it can use a lower condensing temperature, as shown in Figure 4. Variants on these approaches include double flash systems, used at Wairakei in New Zealand and elsewhere, and double binary (two working fluids), used at East Mesa, California in the 10 MWe plant built by Magma Power Company. A combination of a flash stage followed by a binary stage would have the advantages of high efficiency and cost savings, with the flash condensate providing the binary makeup water and with a small preflash used to bleed off non-condensible gases and to top off the binary cycle for maximum energy recovery. Such a combination has not yet been built, but appears attractive.

Various schemes have been proposed for passing the total fluid flow through a single energy extraction system, saving complexity at the possible cost of some efficiency. The earliest successful machine of this type was the Sprankle Helical Screw Expander, and a 1 MWe wellhead generator of this design, developed and tested under DOE funding, is to be demonstrated in several countries under arrangements by the International Energy Agency.

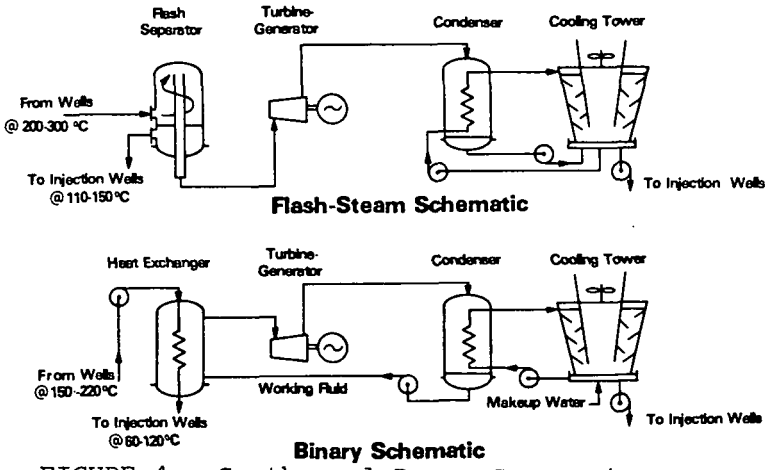


FIGURE 4 Geothermal Power Generation

The cost of generating electrical power from hydrothermal resources in the U.S., estimated by DOE contractors last year, varies from below 4 cents per kWh to about 9 cents per kWh assuming success of technology improvements now underway. These costs compare favorably with power generated from coal in the western states (4.8 cents/kWh) and from oil at $26 per barrel (9.6 cents/kWh), and emphasize the importance of geothermal power generation as a replacement for oil.

Rapid economic expansion in the Phillipines has brought rapid development of geothermal resources with the help of field development by Union Oil (USA) and KRTA (NZ). Mexico has expanded its Cerro Prieto field near the California border and sells surplus power to the U.S.; there are plans to develop the Los Azufres field near Mexico city and other areas in an aggressive program. Japan has a concerted effort between government and industry to build a significant amount of geothermal generating capacity in the next twenty years, in spite of the best geothermal prospects being in national parks whose beauty must be preserved. Italy, New Zealand,

Iceland and at least six Latin American countries are planning to add new generating capacity in the next five years.

In the U.S. the growth surge at The Geysers in the early 1970's was followed by a hiatus coincidental with the promulgation of environmental guidelines and the proliferation of legislative, regulatory and jurisdictional activities that followed actions by Congress to promote geothermal development. However, growth at The Geysers has resumed and some seven additional 110 MWe plants are to come on line by 1986. For many years the Imperial Valley of California has been seen as another significant growth area for geothermal power, and the vanguard of development there is the unique 10 MWe Magma double-binary plant operating at East Mesa using the Magmamax process, followed closely by Union Oil/Southern California Edison's 10 MWe flash steam plant which is on-line at Brawley. Other plants have been announced by industry at Heber, Brawley, East Mesa and Niland. The cost-shared efforts by DOE and San Diego Gas & Electric to solve the problems of highly saline brines at Niland, and to demonstrate the commercial parameters of a 50 MWe binary plant at Heber have done much to accelerate the exploitation of the Imperial Valley's resources where 500 MWe of power from liquid-dominated resources could be on line by 1985. The construction of a 50 MWe flash-steam plant at the Valles Caldera in New Mexico under a cost-shared agreement between DOE, Union and Public Service of New Mexico will provide much needed technical and economic data for the development of high temperature liquid-dominated hydrothermal resources in the U.S.

b. Direct-Heat Applications

In the U.S. about 60% of the total energy consumed is used for heating, and more than half of this heat is supplied at temperatures below 100°C. Geothermal resources at low (< 90°C) and moderate temperatures (90-150°C) that cannot be economically used for power generation occur in 38 states (Figure 1), and the number of known reservoirs far exceeds those of high temperature. For example, four hundred communities with potential geothermal resources have been identified in the Rocky Mountain States alone. These resources can be harnessed and used directly, without conversion efficiency losses, wherever a user and reservoir are close together.

Residential, civic and commercial space heating consume more than half the heating energy in the U.S. and this use is the biggest target for geothermal heat. District heating systems, and space heating of schools, hospitals and office buildings are being planned and adopted in increasing numbers as heating bills rise. The production of ethanol as a fuel is energy-intensive, and geothermal resources can in many locations provide the energy for digestion and distillation. Agricultural uses include the raising of crops in greenhouses and by soil heating; and food processing by drying, cooking, freezing and canning. Other industrial uses include drying of lumber, pulp and paper manufacture, chemical extraction, concrete drying, textile manufacture and processing, sulfur mining and brewing.

The costs of using geothermal heating vary widely with well depth and temperature, distance to the user, type of application, and efficiency of use. Battelle Pacific Northwest Laboratories[5] has developed a cost curve in 1979 dollars for using the 90-150°C hydrothermal systems identified by the USGS 790 that shows that half of these resources could be used for less than $8 per million Btu, roughly the cost of oil heating, and 90% of them for less than $11 per million Btu, roughly the cost of electric heating.

The cities of Boise, Idaho and Klamath Falls, Oregon, which have had district heating systems since the turn of the century, both have new district heating projects under construction. DOE is cost-sharing these projects and six other district heating systems. DOE is also supporting space-heating installations in the THS Memorial Hospital, in Marlin, Texas, and ten other space-heating projects that include three more hospitals and two schools. The Holly Sugar plant at Brawley, California is converting to geothermal operation of the boilers and dryers for refining beet sugar, with DOE support. The first geothermal ethanol production facility is in operation at LaGrand, Oregon, and Bechtel has completed the conceptual design of a large ethanol plant for Raft River, Idaho. Other ethanol plants are at various stages of development in Utah, New Mexico, California and Oregon.

c. Hybrids

Application of geothermal energy to the drying of wood chips and forest slash to raise the combustion temperature and thus the thermal efficiency of a wood-fired power plant is the unique approach being used by GeoProducts Corporation at Honey Lake, California. This hybrid 55 MWe plant, partly funded by DOE, the U.S. Forest Service and the California Department of Water Resources, also uses geothermal energy to preheat the feed water for the boiler. It is expected to be on line in 1984 and may be followed by many similar plants in California and Oregon.

The city of Burbank has actively pursued the concept of a hybrid coal-geothermal plant in which the geothermal fluid is used for coal beneficiation as well as feed-water preheat. Such a plant has favorable economics, but various factors including complexity, large commercial size and instutional problems have obstructed its adoption as yet.

The Federal Program for Geothermal Energy

As the lead agency, DOE has the role of stimulating the commercial development of geothermal energy. The major activities are:

i. Resource assessment and reservoir confirmation to establish the existence and commercial suitability of geothermal reservoirs. For high-temperature resources, DOE has sponsored an industry-coupled cost-sharing program to confirm the existence of resources for electric power production in Utah and Nevada. For the developers interested in direct uses but are not ready to assume the full risk until a reservoir has been confirmed DOE has sponsored several programs including state-coupled resource assessment, and cost-shared, user-coupled reservoir confirmation for low- to moderate-temperature resources.

ii. Research and technology development to reduce the cost of geothermal field development and energy conversion, and to increase efficiency and demonstrate resource reliability. The activity comprises programs in exploration technology, reservoir engineering, geochemistry, materials and reservoir stimulation. These will result in better siting criteria for well drilling, better definition of geologic and reservoir performance parameters (flow rate, recharge rate, ultimate life, etc.), less expensive and corrosion resistant materials and increased well flow rates resulting in lower geothermal fluid costs.

iii. Component development activities, cost-shared with industry, to reduce the cost of drilling and energy conversion equipment, particularly for moderate temperature resources where high development costs are impeding development by the private sector. Environmental control equipment is also being developed to mitigate adverse environmental impacts of geothermal development.

iv. Design, construction and operation of pilot-scale facilities to demonstrate new energy conversion equipment and processes and to resolve site-specific problems such as cooling water availability, injection of high-salinity brines, and cost-effective energy conversion for moderate temperature resources. Present facilities are the 5 MWe Raft River Binary Pilot Plant, in Idaho, the 3 MWe Hawaii Wellhead Generator; and the 20-50 MW (thermal) Hot Dry Rock Thermal Loop at Fenton Hill, New Mexico.

v. Industrialization activities to encourage and provide data on cost, risk and experience, and to encourage the private sector to develop and use hydrothermal resources for electric power and direct heat applications. A variety of marketplace activities are conducted, including the 50 MWe flash-steam demonstration project in New Mexico, the 50 MWe binary demonstration project in California, direct-use projects of many types, site-specific industrialization planning, market penetration studies, and engineering and economic feasibility studies.

vi. The Geothermal Loan Guaranty Program that minimizes a lender's financial risk, so that credit can be made available for field development and construction and operation of geothermal projects.

The budgets for the Division of Geothermal Energy's program in the current and coming years are estimated at the time of writing to be as given in Table 2.

TABLE 2. DGE's Budget (Estimates)*

	Dollars in Millions	
	FY 1980	FY 1981
Hydrothermal Industrialization	71.0	63.0
Geopressured Resources	36.4	34.5
Geothermal Technology Development		
Hot Dry Rock	15.0	14.0
Component Development	26.2	39.5
Program Direction	2.0	2.6
Total Budget Authority	150.6	153.6

*Not including Loan Guaranty Authority for FY 1980 at $350 million and for FY 1981 at $200 million.

Also at the time of writing, the Energy Security Act Title VI (Geothermal Energy Act) provides that the Secretary of Energy shall establish programs to provide loans for geothermal reservoir confirmation and for feasibility studies and construction of direct heat projects, and provides authorization for reservoir insurance and reinsurance depending on the results of a pilot study to be conducted in FY 1981. If funding to implement the provisions of this bill is appropriated the Federal role in geothermal development will be greatly enhanced, and the chances for reaching projections discussed earlier in this paper would be substantially increased.

Although the DOE role in most of the hydrothermal projects in the U.S. has already been mentioned, and the major program activities have been described in general above, no discussion of the DOE program would be complete without highlighting some of the technology advances being made for the future. Future binary

systems will be able to use direct-contact heat exchangers that will reduce plant cost -- a 100 kWe direct-contact power system was installed and operated successfully at Marysville, Ark. from a 96°C resource. A 500 kWe direct-contact binary plant is operating successfully at East Mesa, California. The Sperry thermal pump binary system under development uses a downhole heat exchanger and promises very high efficiencies. Newly designed drill bits and total drilling systems will lower drilling costs by at least 25 percent in the near term, and the target reduction is 50 percent. Well stimulation programs will reduce the number of unsuccessful wells, and improved well completion techniques will improve well life. New low-cost polymer-concrete materials for reservoirs of all temperatures, and new instruments for exploration, logging and monitoring are being adopted in current projects. The results of these programs together with the technical and economic data arising from the demonstration and pilot plants will provide industry with the important information needed for rapid growth.

Developments in Hawaii

Hawaii is unique among the 50 states since it has to bring fossil fuels thousands of miles to the islands. However Hawaii does have favorable conditions to employ every one of the alternative energy systems discussed at this conference, and their adoption will depend primarily on economics and secondarily on their acceptability and the contribution they can make to improve the employment picture.

It is difficult to make objective comparisons between the energy alternatives, because the proponents of each become crusaders when it comes to providing data for selection. Nevertheless, it is easy to show that one leading contender is geothermal energy.

There are a number of key issues surrounding geothermal development in Hawaii:

i. Although the known geothermal resources are not where the population is most concentrated (i.e., Oahu), electricity generated on the Big Island could be transmitted to the other islands with a deep sea cable or else the user could be co-located with geothermal resources on the Big Island. Alcohol, or other fuels, can be produced with the assistance of geothermal energy for shipping to Oahu.

ii. Geothermal energy has been declared to be a mineral by the Hawaii State Legislature. However, since the ownership rights of minerals for much of the land in Hawaii belong to the State, many of the land owners in Hawaii question the State's interpretation. In addition, the Native Hawaiians feel they have a claim to the geothermal resources. The ultimate disposition of geothermal ownership rights may have to be resolved by the courts.

iii. The County of Hawaii (Big Island) and the State have for many years carried out cooperative planning together with the University of Hawaii on energy issues, with emphasis on geothermal developments. However neither government group nor the local utilities have been able to fund significant geothermal developments until recently, due primarily to the limited market for increased electrical capacity on the Big Island.

iv. Prospecting for geothermal fluids has been limited. DOE, and its predecessor ERDA, supported the state and county-sponsored University of Hawaii project that drilled the HGP-A Pohoiki well in the Puna district and is currently

installing a 3MWe wellhead generator at the site. The two years of testing planned will provide experience in the long-term drawdown of the reservoir, while selling the power commercially through HELCO to defray some of the project costs. The regional geothermal resource assessment completed last year by the University of Hawaii's Hawaii Institute of Geophysics resulted in targeting intensive site-specific studies at Kawaihae and Keaau on Hawaii and Lahaina on Maui, with additional preliminary surveys being performed on Hawaii, west Molokai, east Maui and part of Oahu. Some 20 areas have been identified and studied, seven of them with commercial potential.

DOE cost-shared planning activities with the state and county have assisted in paving the way for many current private developments. The state Geothermal Advisory Council held its June meeting in Pahoa in conjunction with the Geothermal Symposium organized by the Puna Hui Ohaua. This and the many other coordination activities conducted by state and county teams have served to provide effective information exchange on physical and social issues surrounding geothermal development. The County of Hawaii has made $1.5 million available for a step-out well near the Pohoiki well HGP-A for a project that may involve papaya processing and ethanol production. Bishop Estates, Natomas (Thermal Power of San Francisco), and Dillingham (Hawaii) plan a joint venture on the Bishop and Lyman estates in this area. Barnwell Industries (Tennessee) in a joint venture with GEDCO of Honolulu spudded their first well near Puna this June. County approval for six wells for the joint venture was followed by a request for nine more wells. Together with the Bishop-Natomas-Dillingham venture there will be 12 new wells drilled in Hawaii by the end of 1981.

Looking ahead, Dillingham's subsidiary, Hawaiian Dredging and Construction Company, is planning a venture with GeoProducts of California for an ethanol plant using Puna Sugar Company bagasse processed by both geothermal energy and bagasse-waste burning. This would be part of the Pahoa Industrial Park they are planning, which is to include papaya processing, cattle feed from cane leaves and protein from haole koa trees.

Lockheed has, for some time, considered the processing of maganese nodules using geothermal power from Puna, but no negotiations for a site either inland or near the shore have been announced. Much consideration has been given to processing bauxite in Hawaii, on its way from Australasia to the U.S., but the aluminum companies have not had their Bonneville power cut back sufficiently, yet, to cause them to make firm plans for Hawaii. Mid-Pacific and other interest groups are following Hawaiian developments very closely.

We can expect that Hawaii, with its present dependence on imported fuel, will become a model for the Pacific Islands in the rapid employment of its geothermal resources, with appropriate concern for the environmental and social issues. Through collaboration of the state, county and local teams, and individuals, with the industrial interests, we may see Hawaii surpassing other states in the pace of adopting geothermal energy as the preferred energy resource.

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PHOTOVOLTAIC OVERVIEW

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Introduction

Photovoltaics is a simple and an elegant technique for converting sunlight to electricity. In fact, it is the only process for converting solar energy directly into usable electricity. Photovoltaics has many desirable characteristics: It requires no moving parts, generates no noise or vibration, and produces no thermal or chemical pollution. It is an energy conversion approach very much in harmony with an environment such as Hawaii.

It is difficult for the general public to perceive the exciting growth of this technology since the beginning days of the space program when tiny solar panels energized the early satellites. Their output, a few dozen watts, is dwarfed by such recent photovoltaic systems as the Air Force radar station at Mount Laguna, California, which generates up to 60 kilowatts. Another large system provides all the power for the Papago Indian village of Schuchuli in southern Arizona, operating water pumps, refrigerators, sewing machines, and lights.

Photovoltaics are now cost-competitive in many remote sites. As their cost continues to decrease, they will be competitive for many more applications isolated from the utility grid, for decentralized installations, and well suited to photovoltaic power. Futhermore, there appear to be no technical or economic barriers to integration of megawatt photovoltaic power plants into the existing utility power grids in the not-too-distant future.

The range of applications for photovoltaics, therefore, is expanding as rapidly as its cost drops and other energy costs rise. Figure 1 illustrates the relationship between the price of photovoltaics, the size of their market, and their cost-effective applications over time. The cost decrease illustrated is based on meeting DOE cost goals.

The major focus of this paper, then, is an overview of photovoltaics as a large-scale energy source, the various types of photovoltaic systems, and a brief discussion of its cost reduction potential.

History

The system in operation today represents significant progress in a rather short time from the real beginning of photovoltaics as a power generating technology. This beginning can be traced to the invention of the silicon solar cell in 1954 at the Murray Hill, New Jersey facility of Bell Laboratories.

It had been observed that sunlight falling on a silicon semiconductor created an electrical disturbance within that silicon which interfered with the device's performance. That is one of the reasons transistors today are enclosed in a can or covered to protect the chips from light-generated interference.

The phenomenon was well understood even in 1954 as a manifestation of the photovoltaic effect, an effect first observed a century before by Becquerel, and nicely modeled by Einstein in 1900. What Einstein postulated and what still fits today is that light energy, even though it

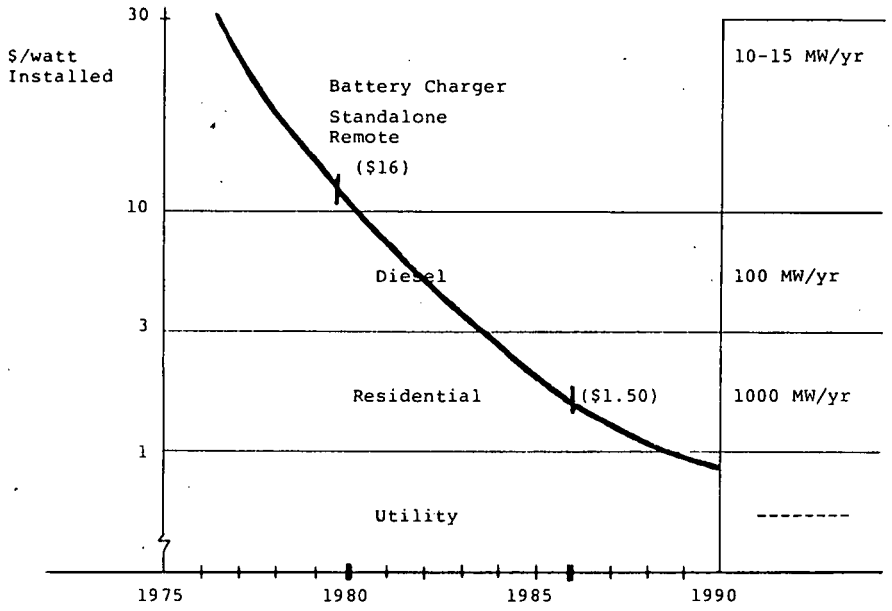


Fig. 1 Relationship of Photovoltaic System Cost and Potential Market Size vs Time

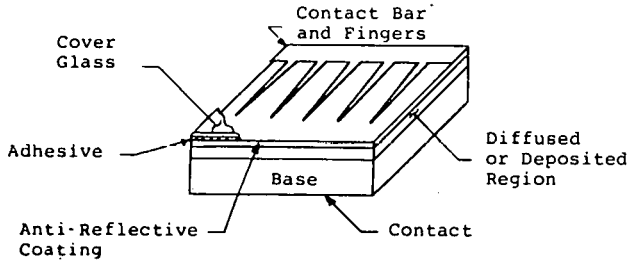


Fig. 2 Typical Solar Cell

appears continuous, actually comes in packets of energy called quanta or photons, and when one of these photons collides with an electron, it gives up all of its energy to that electron.

What Becquerel and the semiconductor scientists at Bell Laboratories were observing was that these collisions could free an electron from its atom and make it available for conduction of electricity. A photovoltaic device is constructed with a built-in electric field which causes these electrons to flow in one direction, thereby resulting in usable electric current.

Figure 2 illustrates the typical components of a solar cell. Its primary features are:

a. A base of one electrical type ("p" or "n") of seminconductor material;

b. A diffused or deposited region of the opposite electrical type of semiconductor material;

c. An anti-effective coating on the cell front to maximize light absorption; and

d. Electrical contacts and collectors on cell front and back (front contacts are gridded to allow light into the cell).

Some cells are covered with a thin glass slide which protects them from the environment.

Silicon solar cells, which dominate the commercial photovoltaic field today, generate a potential of about half a volt each, with their current output depending primarily on surface area. In full sun, good cells ($\sim$ 16 percent efficiency) can produce as much as 35 mA per cm^2. Some large terrestrial cells produce over two amperes of current.

Short-circuit current is also directly proportional to incident light intensity, with open-circuit voltage relatively independent of light intensity. Power output decreases about 0.4 - 0.5 percent per ^{o}C increase in temperature.

For most terrestrial applications, cells are packaged in solar panels or modules which provide structural support, protection from the elements, and units which are mechanically and electrically convenient. A cross-section of one type of module is shown in Figure 3. Such modules are sometimes termed "flat-plate" photovoltaics, a term which differentiates them from concentrator photovoltaics.

Concentrator photovoltaic systems use mirrors or lenses to increase the intensity of light incident on specially designed cells. Since current output is directly proportional to light intensity, such a system can produce increased power without commensurately increased cost. They accomplish this by, in effect, replacing costly cells with relatively inexpensive structural material. An added advantage can be gained since many cells actually increase in efficiency as a function of concentration. Figure 4 shows plots of efficiency versus concentration for typical silicon concentrator cells optimized for performance at 10, 20, and 40 suns. Concentrator systems are now undergoing prototype and field evaluation. When their technical complexities are resolved, they may become serious competition for flat-plate systems in some applications.

Silicon photovoltaic systems have been used for a host of applications for many years, but the first real demand for this technology came from the space program. Photovoltaic systems for spacecraft were originally considered to be just a stopgap, providing power until nuclear power plants could be developed. However, they proved so technically and economically compatible with spacecraft they were never displaced, and still are the principal power

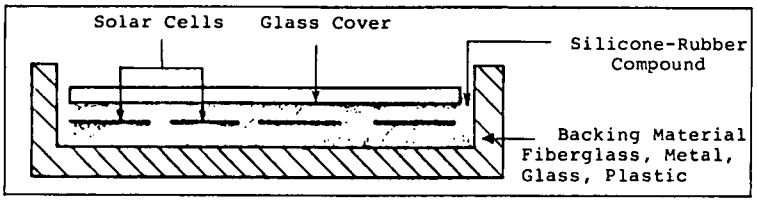


Fig. 3 Cross-Section of a Photovoltaic Module

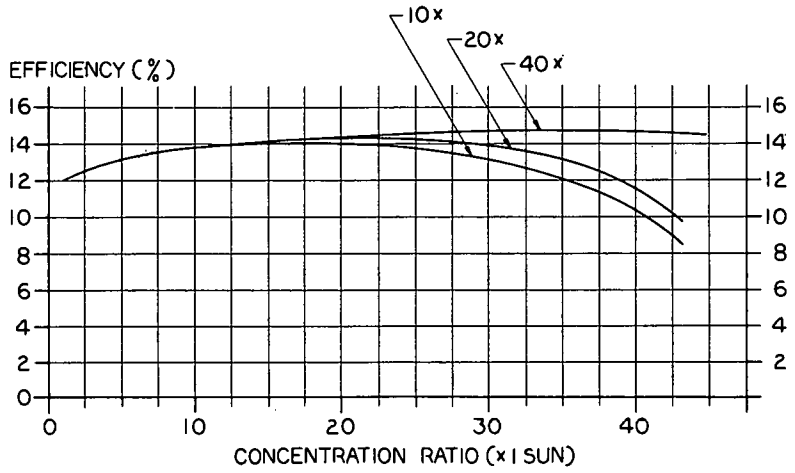


Fig. 4 Cell Efficiency as a Function of Concentration Ratio

systems for spacecraft missions. Their scalability, reliability, and durability were closely evaluated during this early period and they were found to be simple and exceptionally reliable. They were also demonstrated to be very modular in nature, since power, voltage, and current are directly and simply related to the number of appropriately interconnected cells and panels. A small terrestrial photovoltaic system business also evolved during this period. Early terrestrial systems powered very modest, remote applications and were built with reject cells from the space program. Serious development of the terrestrial photovoltaic industry, with resources committed to the manufacture of photovoltaics intended for earthbound uses, did not begin until 1973 or 1974.

Present Status

In recent years, systems have become larger, more varied, and more complex. A number of applications have proven particularly adaptable to photovoltaic power, including remote communications stations, navigational aids, cathodic protection of steel structures, water pumping in developing areas and nations, and remote housing. Electrical outputs of some of these systems are DC, some AC; some are stand-alone and others are designed to be interactive with other energy sources, including utility grids. A block diagram of a typical stand-alone system is shown in Figure 5.

Substantial progress has been made in reducing the cost of solar cells and directly related components such as cell encapsulants and interconnects, and increasing attention is now being focused on reducing the cost of other components of photovoltaic systems. Known as BOS (balance of system) items, these include the array structural support systems, array wiring, AC-DC inverters, and energy storage techniques. Improving the efficiency and cost figures of these BOS items becomes increasingly important as the parameters of the primary system elements improve.

There are literally hundreds of gases, liquids, and solids which have shown a photovoltaic effect. The variety of these materials and their combinations will keep researchers busy for many years to come. The standard of today's photovoltaic technology is silicon, the only device material which has reached commercial readiness as an electrical power source. Cadmium sulfide follows silicon in popularity, but is an extremely distant second.

Presented in Table 1 is a summary of the major photovoltaic technologies being investigated today. An arbitrary major division of these technologies results in Ingot, Ribbon, and Thin Film categories. "Ingot" means that the basic material is crystallized or otherwise shaped into ingots (either cylinders or rectangular solids) and then cut into thin wafers from which cells are made. Ribbon technology seeks to eliminate the need for cutting and go directly to a thin wafer from molten material. These ribbon techniques usually involve an approach like extruding the material through a die, much as one extrudes aluminum or plastic. Thin film technology seeks to apply a very thin coating of photovoltaic material on a low-cost substrate, much as one paints his home or metallizes glass to make into a mirror. There is no doubt that a low-cost, thin film technology which could provide efficiency and stability equivalent to that of today's ingot silicon cells would be very competitive. But such technology has not yet been developed.

Because of the billions of dollars invested in silicon semiconductor technology, silicon solar cells have an enormous technology base which is permitting very rapid development. Not surprisingly, the major production breakthroughs are occurring in ingot silicon, and this is one of the most promising approaches to achieving the cost goals set by the Department of Energy for the end of the 1980's.

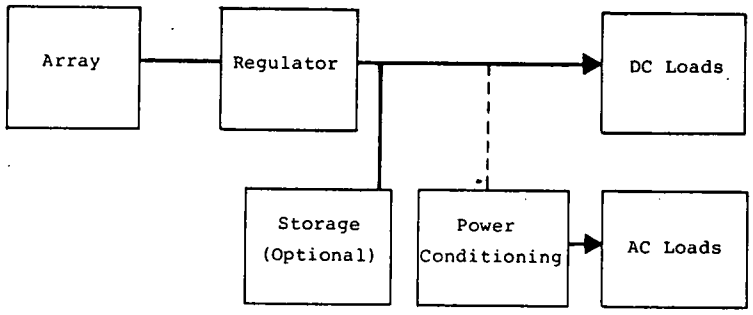


Fig. 5. Components of a Solar Power System

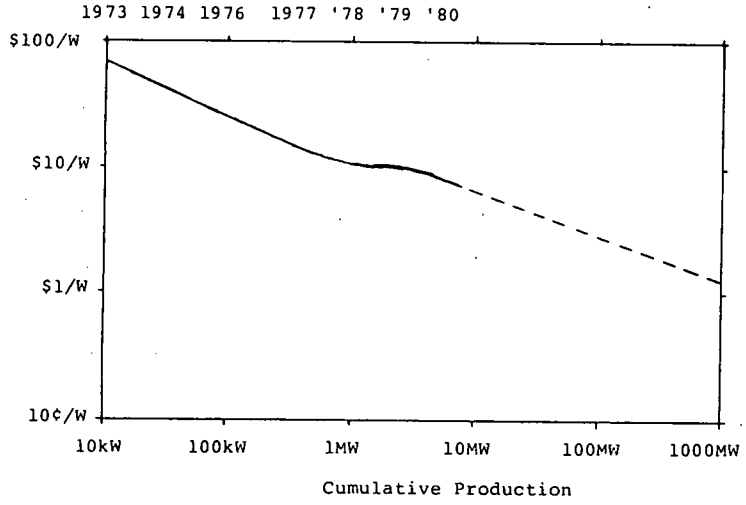


Fig. 6 Experience Curve, Terrestrial Photovoltaic Production vs. Price

Table 1. PHOTOVOLTAIC DEVICE CONVERSION TECHNOLOGIES

MAJ. DIVISION	TYPE		HIGHEST REPTD EFFCY.	STATE OF TECHNOLOGY
Ingot	Silicon	Single Crystal		
		(1X) Conventional	19	Commercialized
		Concentrator	21	Commercialized
		Advanced	17	Adv. Laboratory
		HEM	17	Near Commercialization
		Semicrystalline		
		Semix	17	Commercialized
		Wacker	12	Commercially available in small quantities
	Ga As	Single Crystal		
		Conventional	19	Commercial in small qty
		Concentrator	25	Commercial in small qty
Ribbon	Silicon	Dendritic Web	16	Pilot Plant Study
		EFG	14	Advanced Laboratory
		ESP	14	Laboratory
		RTR	12	Advanced Laboratory
		Silicon on Ceramic	10	Laboratory
Thin Film	Si/Simg/Graphite		10	Pilot Plant Study
	Amorphous Si on glass		6	Laboratory
	CdZns/CdS		9.5	Laboratory
	CuS/Cds (Evaporated)		9	Possibly near Comm. Readiness
	CuS/CdS (Sprayed)		6.5	Possibly near Comm. Readiness
	GaAs on Graphite		8	Laboratory
	CuInSe/CdS		9.5	Laboratory
	CdTe/CdS		8	Laboratory
	Cu_2O		1	Laboratory
	$InSnO_2$/CdTe		8	Laboratory
	InP/CdS		6	Laboratory
	Organic		1	Laboratory

'ath Toward Low-Cost Photovoltaics

The cumulative sales of the photovoltaic industry and the average per-watt price for hardware is shown in Figure 6. This indicates that there has been both significant growth and price reduction, particularly since 1974, the advent of the terrestrial business. It also indicates that the industry is following what is known as an 80 percent learning curve. Such a curve indicates that product price is dropping 20 percent with each doubling of quantity produced. This curve is very similar to the learning curve demonstrated by the transistor industry between 1960 and the present.

Numerous analyses by both government and private firms have predicted a rapidly increasing role for photovoltaic power in the world's energy mix. One of the more interesting analyses indicates that a residential photovoltaic system used in a grid-interactive mode could be price-competitive with utility power for distributed residential applications in six to eight years. Furthermore, this analysis did not consider the effects if subsidies or other incentives, which could considerably hasten attainment of this competitive level.

Nonetheless, when comparing today's photovoltaic prices with DOE goals and forecasts, it is obvious that substantial progress will be required to achieve the goals and meet the forecasts.

What, then, leads us to believe that photovoltaic manufacturing technology can be improved and prices will be reduced to these levels? An important factor is that most of today's industry uses a low-volume, labor-intensive fabrication approach and is based totally upon technology which requires extremely pure materials and expensive equipment. For example: Silicon material produced from sand or quartz is chemically refined to parts per-billion purity and ingots are grown slowly and meticulously from that extremely pure material. This growth is very slow, producing 3- to 4-inch-diameter ingots at a rate of 2 to 3 inches per hour in precisely controlled machines which cost over $200,000 each. Present techniques for fabricating solar cells and panels from these ingots are also relatively slow and very labor-intensive. There has been little utilization of mass production processes because the market is only now becoming large enough to justify capital investment for high-volume tooling.

In silicon photovoltaic technology, there is no single "breakthrough" that will give overwhelming cost reduction: improvements are necessary in all areas including material purification, wafer preparation, and device and array manufacture. The feasibility of many of the technology improvements necessary has been individually demonstrated.

The effort necessary to bring all these cost effective technologies to production readiness is still quite significant, but there is no doubt it can happen. The major question is when, and that is a many-faceted, very complex question that involves industry commitment, market justification, and government encouragement. In the meantime, the photovoltaic industry will continue to grow and improve on its own merits because there is a basic need for the product, and there is a sound technological foundation on which to build.

The practical value of obtaining experience in system design, installation, operation, and maintenance is important. There have been and will continue to be engineering problems in many of these test installations; that is as it should be because of their first-of-a-kind nature. It must also be anticipated that legal, social, and/or operational problems must be faced and solved before this will become a totally ready technology.

The record of success has been good to date. It is difficult to believe that a more benign, and hence a more desirable energy source can be found to fit Hawaii's needs in the future.

SOLAR THERMAL ENERGY SYSTEMS PROGRAM OVERVIEW

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I am very happy to be here in Honolulu--especially in December--and talk to you about solar thermal energy systems and show you some actual hardware. I think you will agree from the photographs that we are making a great deal of progress.

This is a quote from the Wizard of Oz that I have been thinking about ever since a couple of months after I joined DOE. "It really is a different world there." Whatever we hope to accomplish in solar energy is going to be very much determined by how we can relate that very different world (and what it is capable of) to the industrial/utility world (and what it is capable of).

Solar thermal systems, to be very trite, produce heat, and that is important. The first practical use of one of our major technologies was the central receiver. At least it is rumored that the central receiver concept was used by the Greeks to burn holes in an invading fleet's sails. This was something that Archimedes came up with, and while we cannot confirm whether it was successful and at what heat flux, ever since then there has been some interest in this technology. More recently--within the last hundred years--the distributed collector techologies have been similarly demonstrated in terms of technical feasibility.

To perhaps point out the obvious, there are several ways of looking at energy. One way is to recognize that most of the energy we use in the United States--whether it is used for lighting or performing mechanical work or direct heating or to cool things--passes through the stage where it becomes heat, which is made usually by burning a fuel. Indeed, now and increasingly in the future, the markets for heat at higher temperatures are going to be dominant in the total national energy perspective. By the year 2000, well over half of our national energy requirements will be served by taking heat and applying it directly through industrial processes, or taking heat and converting it to electricity in thermal power plants.

Concentrating solar collectors are the best means to get the heat, if you want to use solar for these purposes, for the simple reason that non-concentrating solar collectors cannot produce the requisite temperatures to satisfy more than a small share of the industrial process heat market, and certainly cannot produce steam conditions anywhere near compatible with modern turbine plant equipment. We are, therefore, focusing our effort on several major categories of concentrating collectors. Shown here is the linear parabolic trough type collectors that are now actually being marketed commercially in this country primarily for process heat and lower temperature building applications, but we have also demonstrated them in electricity production.

Another distributed collector type is the parabolic dish which concentrates sunlight on a single receiver rather than a line. These two collectors are at our test site in California that is operated at Edwards Air Force Base by the Jet Propulsion Laboratory. This, many of you will recognize, is another type of

collector: a heliostat, essentially a flat mirror which is used to redirect sunlight to a boiler or a receiver--an air heater for example, that is ordinarily located at the top of a tower so that the reflected sunlight is not shaded or blocked by being beamed along the ground.

Another concept is the fixed hemispherical bowl concept. This is a DOE funded test bed of that concept which was completed late last year and is in operation now. It is about twenty meters in diameter and produces steam at roughly 950°F, 1,000 psi. The heliostats have for some years in test facilities been integrated into operating systems, primarily to provide heat for various experimental purposes. This facility, located at the Georgia Institute of Technology, was funded by the Department and is now used in our program for testing very high temperature receivers at scales of a few hundred kilowatts thermal.

Likewise, we have tested a large number of individual distributed collector designs. This is an aerial view of the intermediate temperature test facility that Sandia Laboratories operates for us at Albuquerque. Here we have tested and distributed collectors in full system operation, as well as tested a large number of individual/industrial designs to help the designers get them to where they should be by design calculations, from where they actually start when you first put them on test. Usually there is a substantial difference.

I would like to indicate to you how the solar thermal programs of DOE relate to the "Quad Wars". As you know, about a year ago the President said that we would try to get 20% of our energy in the year 2000 from various sources attributable to solar. It is interesting that when that is broken down--based on the guidance and advice that he received--most of that is expected to come from things that are indirectly solar or things that we have done in the past, are doing now, or should know how to do very soon. That is, about two-thirds is expected from things like hydro, biomass, wind, passive design, etc. Direct collection of sunlight, for various purposes, is expected to contribute about one-third, including about one quadrillion Btu's equivalent of electricity from photovoltaic devices. (By the way, a quadrillion Btu's is like 180 million barrels of oil--it is a lot! The national consumption is about 70 to 80 quads per year right now.) Five quads per year then are expected, or hoped for, from thermal collectors for the purposes indicated there. Accordingly, for concentrating collectors, we have accepted a goal of producing three quads per year by the year 2000.

We have invested something close to $300,000,000 in the development of these types of systems. A good deal of research, development, and actual hardware work has been done. We are now increasingly focusing on getting products qualified. Essentially, what we want to have available in the near future in the industrial process heat area are catalogue items--boilers that can be ordered from catalogues, if you will, and modular thermal electric devices that range in scale from tens of kilowatts to even tens of megawatts. For some time, we have had the goals for what these products and these packages have to cost in order to be competitive. Our goals for electric devices and systems are in the range of $1,000-$2,000 per kilowatt, depending on the application--$5-$10 a million Btu, which I guess can be roughly translated into $30 to $60 a barrel oil. In order to do that, collectors of the type that I have been describing have to cost in the range of $7-$14 per square foot. The designs we have produced to date--not the designs that have already been built as prototypes--have been studied by people like General Motors, who should know what it costs to mass produce things. They concluded that these collectors seem to be producible at somewhere in the range of $7-$14 per square foot--based on production rates that are equivalent to say 10,000 to 20,000 collectors a year, or say one 100 megawatt plant's worth of heliostats each year. We

have been tracking very closely the cost of heliostats, the key ingredient to a central receiver, and were very anxious to find out what heliostats for the ten megawatt pilot plant actually would cost. We had done some estimates back in mid-1976, which said that the heliostats for our test facility ought to cost in the neighborhood of $40 to $80 a square foot and that the pilot plant heliostats ought to cost somewhere in the range of $25 to $30 a square foot, with the goal ultimately being about $10 a square foot. We're pleased that the heliostats for the pilot plant came in at roughly $30 a square foot, in spite of the rather significant changes in economic conditions that have taken place in the last three years.

We are trying to make sure that the development being product-focused, is also market-focused. We think that the parabolic trough collectors are very good for process heat applications in the range between less than 200°F to perhaps as high as 600 to 700°F. We feel that central receivers are the best approach for larger scale applications for both electric power and process heat; and we are very intrigued with parabolic dishes for their modularity and producing very small packaged electric systems that will ultimately compete very well with photovoltaics.

The initiatives that we are taking now with the budgets in the next couple of years will be to follow the Barstow pilot plant activity with projects in the area of what we call repowering--taking a solar boiler and putting the steam from it into an existing turbine plant by locating the solar boiler adjacent to the existing site.

Also, we're very interested in a comparable application to enhance oil recovery where, instead of a fossil boiler, you get steam from the solar equipment to inject into the ground and enhance the production in areas of very heavy oil deposits--for example, in California. I might add that, just to show that DOE and SERI are not in lock step on all issues, SERI says some very pessimistic things about the application to enhanced oil recovery. We think SERI is wrong. In fact, there is some good evidence of it in the fact that several major oil companies are looking--not only working with DOE in this matter, but going ahead alone without DOE--to install prototype systems to take advantage of some of the federal laws that are in effect to encourage such activity.

This is one of several industrial process heat demonstrations that have been employed in the last couple of years. We are not actively building larger and higher temperature industrial process heat demonstrations to get the direct user and supplier interaction that is necessary to the commercialization process.

This is an artist's conception of the application of the power tower, the central receiver, to enhancing oil recovery. It is one of six conceptual designs looking at industrial heat retrofit applications that are very nearly complete and will be considered now for the next--essentially demonstration--phase of the program.

Here is an artist's concept representative of several other projects for electric utilities repowering applications--this one being conducted by Black and Veatch in cooperation with Public Service Company of Oklahoma.

We have just completed thirteen of these projects (twelve studies funded by DOE, one funded by West Texas Utilities and Rockwell) that are distributed as indicated here. I think that the distribution indicates something that has been a historical pattern in the solar thermal program, and that is that interest was first in the Southwest. This was due perhaps to a perception that solar is only good in the Southwest. It is true that it is better there, but more than half of the country in terms of the quality of the resource is within a factor of two

of the best conditions in the country--for example, in the middle of Arizona or in the middle of the Mojave desert in California.

In preparing the way for such projects, we have underway a 10 megawatt central receiver pilot plant project. We've completed preliminary design on this project, have signed a contract for the heliostats, and in fact, have decided within DOE to give the project its final release for construction. At this point, the next gate the project has to get through in DOE is to be allowed to start operating.

Meanwhile, there is activity associated with the normal budget process to consider all solar programs, and whether money is available in their existing budgets to deal with some of the budget cutting initiatives that are active in the Congress. That process is going on and it will probably continue for the next couple of weeks or more. Whatever happens, we expect Congress will do precisely what is in the best interest of the country, and the process at this point is not complete by any means.

The site for the 10 megawatt pilot plant is near Barstow, California, where there are four existing combined cycle plants operated by Southern California Edison. It has been graded and although this photo is a little old, more than half of the foundations for the heliostats--essentially just concrete piles--are in place. There is a visitor's center there if any of you would like to visit this notorious location.

Much of the preparation for this project has focused on the use of the five thermal megawatt Central Receiver Test Facility at Albuquerque. What you see here is a single full scale panel of the 24 that would comprise the pilot plant receiver on test on the top of the tower using essentially the full heliostat field capability. That test was successfully concluded a few months ago, so we're confident of the success of the overall project. In addition, the test facility has been used to test and characterize, qualify and select the heliostat design for the full project.

One very important area of exprience at the test facility is how you operate and run this whole system. The experience has proved very valuable in designing a control concept for the pilot plant. This is essentially a single operator concept that allows the pilot plant to be operated much as and perhaps even more conveniently than so-called conventional power plants.

I mentioned parabolic dish technology, which we feel is important for community scale electric application. We have underway a program to build a one megawatt community scale pilot power plant using parabolic dish technology. We have received upwards of forty proposals from interested communities and municipal utilities around the country and are in the process of selecting a primary site and perhaps alternate sites for this type of activity. This project is somewhat farther behind in schedule than things like the Barstow project and will probably be completed in mid-1983.

The very small package supported by the struts on the dish in principal can comprise a full thermal power plant with either an organic Rankine cycle engine coupled with a steam receiver of something like that, or Brayton cycle turbine coupled with an air receiver and a generator. This is what you might call a mini-power plant that you can use to build up in steps any amount of electric generation that is required.

One other project in the community electric area that we have been looking at for some time is the hemispherical bowl, a design of a 5 megawatt community scaled

project. We're doing studies related to a site near Crosbyton, Texas with the cooperation of that town and Texas Tech University. That project is approaching a point where we will very soon decide on exactly what path to use to evaluate that technology and how it should proceed.

We are continually looking at other applications than those major focal points I mentioned earlier, including agricultural heat. We have funded something like very close to a hundred very small projects applying thermal collectors to things like crop drying, animal shelter heating, etc. in our agricultural and industrial heat program. We've conducted two projects aimed at irrigation pumping applications. We have two co-generation projects underway: one that will be completed in mid-1981, and another that is in the planning stages--one using parabolic dishes, the other using central receivers. We've looked at other applications as well.

This is a system designed to produce 150 kilowatts electric on a farm near Coolidge, Arizona, using parabolic trough collectors and an organic Rankine cycle turbine. What you see there, the tank that you see behind the collector field, is filled with heat transfer oil which is used for storage.

This is one of the co-generation, or total energy projects, I referred to. This knitwear plant application at Shenandoah, Georgia is at about the same point in its evolution as the Barstow pilot plant. In this case, parabolic dish collectors are used to produce heat to drive a steam turbine for electricity, which then rejects extraction steam into the irons and other equipment that is used at the knitwear plant.

Here is the obligatory chart which shows how we are organized. We have gone through many stages of organization and undoubtedly this will continue--some of them may even be voluntary. This is where we have ended up as of about two months ago--organized by function and reporting to an office of Solar Applications for Industry, recognizing the potential use of solar thermal technology not just for thermal electric applications but the very important near-term use for industrial and co-generation applications as well.

The division is organized functionally starting with research and advanced development, which is where SERI is very heavily involved; technology development activities that receive technical direction through major engineering laboratories, Sandia and the Jet Propulsion Laboratory; systems and applications projects such as some of those that I've shown you, managed usually through our field offices, in particular at San Francisco and Albuquerque. Finally, what we are trying to put together in the new part of this puzzle is a market development activity that will help us recognize that we are making a transition from technology development to commercialization, and put forward those initiatives necessary to deal with the problems of risk and incentives, regulation, etc. that affect both the potential suppliers and potential users.

In general, the research and advanced development activity hinges very much on the development, qualification, and fabrication techniques for materials that are good for solar--making it cheaper, making it better, although not quite ready for actual use in products. In technology development, the thrust is to produce designs that are geared to mass production. There was some reference to that early today. Of course, we are emphasizing cost-shared pilot plants in the applications area as a means of creating a context where the potential solar businessman and his potential customer can work together in a project and understand each other.

The final element is market development. The key thing there is how the federal government can best encourage, facilitate, and aid the process of obtaining private investment in both supply and purchase of equipment.

Funds are distributed in this way, temporarily based on having just reorganized and trying to understand where things logically fit. There is a fairly stable effort in research and advanced development at the level of about $30 million. Technology development is a function that probably is also fairly stable at the level of close to $50 million per year, and this is based on the President's request in fiscal '81. Systems and applications projects and market development will be increasingly the center of gravity of funding in the program in the future; and as you can see, the scale is about balanced now between the first two and the last two.

Here are some of our FY 1980 activities. In July we initiated the production of the heliostats for the pilot plant. We have selected the sites for the small community project. We've initiated and received proposals and intend to fund a number of studies by existing commercial suppliers of parabolic trough equipment. We have complete the thirteen repowering conceptual design studies. We have selected seven contractors for cogeneration concept design studies. Our irrigation experiment, as you may know, is now in operation and the construction of the total energy project will be initiated during Fiscal '80.

I thought I would now shift gears and talk a little bit about things that matter to people, and that I'm sure concern many of you. Everybody knows that solar is great "but it's not feasible economically" and that "solar is only good in the Southwest." Everybody worries about whether you should use solar for big things or little things. Everybody says solar is fine, "but I also need my energy when the sun is not shining."

I think there is a perspective here that needs to be emphasized, and that is that relative to economic feasibility, some solar thermal systems are actually commercially available at affordable prices. Some are not available today, will not be available next year, and if somebody had to build one right now, they might cost as much as a factor of 5 or 10 more than that person could afford. There is a very broad range of where we stand relative to economic feasibility.

I have already mentioned geographic applicability. When you look at that issue in the context of what has happened to energy prices in the last five years, the factor of 2 or so difference between parts of the country in terms of what solar energy is going to cost doesn't seem that significant. In fact, the differences in conventional energy prices, even electricity prices across the country, are far more substantial now than the cost of solar-delivered energy will be.

Centralized versus decentralized--I suppose what I should do is to give them equal billing. In fact, if you look at what we are doing, much of it falls somewhere in between. A 10 megawatt pilot plant is about enough energy to satisfy the needs of a few thousand people, certainly not on the classical scale of centralized generation. It's within a factor of 10 up and down of relatively small applications on the one hand and fairly decent sized utility plants on the other.

The technology is neutral. How it is used and at what scale, I think, is going to be far more conditioned by where we aim our political process and where industry helps aim it, than by where we aim our R&D program.

Finally, thermal energy storage is a bargain if you have a solar thermal system that is economical to begin with. You can operate these systems any number of hours a day that you want; and that will be a decision that is conditioned by the unique circumstances of each individual user.

I think it's fair, having said there are issues related to solar, to say that there are issues related to other alternatives, and I put this chart up with some trepidation. I quite agree with what has been said to date in this conference that we should be speaking of complementary forms of energy in that we will need them all. I believe that one of the things that has hurt solar a great deal is that in the past is the internal conficts saying one kind of solar is better than another, saying decentralized solar is the only way to go, and that utilities using solar for plants is bad. I think that has hurt our overall attempt to deal with our energy problem, but let's look at the matter of alternatives.

Solar has been viewed as a potential alternative; and in the end, I think some day probably some of the things we now view as conventional may well be viewed as an alternative to solar. Actually, however, I think what we're facing now is a situation where everything becomes an alternative, there are no base lines, nothing is assured, i.e.: you know you can do it; you know that it's best; and its just a question of whether anything else can compete.

Looking at things from a utility perspective tends to create a perception that overlooks something that is fundamental. That is that the nation as a whole has to deal with this energy problem; and there are constraints on the conventional alternatives that may not affect any individual decision, but may well in the end and very soon affect the collection of decisions that are made. For example, we do not want to import as much oil as we have been. Nuclear energy is something that we would like to see implemented where possible, but right now we cannot deal with our immediate problems with it. Coal is something that we would like to see used more, but gearing up to use it at a rate two or three times more than we have in the past is a serious issue for the country. Whether any individual or utility can do it or not is perhaps less important than whether every individual utility can do it simultaneously.

One of the things that I constantly deal with is contractors and our laboratories showing me charts like this with qualifications like "if we achieve our goals" and "this happens to be electricity cost for large scale conventional power plants." If we achieve our goals, there's just no choice between solar and oil. It looks like higher capacity factor solar may do okay against things like coal, which of course, is heresy. Nobody believes that or that solar may do well against the absolute minimum cost base load options, whatever they may be. I don't know whether to believe these curves. I would usually tend to take each one and put a safety factor on the results, depending on the credibility of whoever gave it to me; but I think that this is a very important issue for the industry and for SERI to help us collectively understand whether to start believing these kinds of things.

In summary, technical feasibility for solar thermal has long since ceased to be an issue. The goals we have are achievable by some level of heroics; and the issue really is how much of a hero do we have to be to achieve that much solar energy from thermal systems by the year 2000. I suspect that when we find out what it takes, the decision will be perhaps to back off a notch and say, "Well, perhaps we can wait until 2005." We are looking at what we think are opportunistic things--related to windows in the markets, windows (for example) for repowering, and windows that have been created by federal action such as for the new guidance to state utility commissions related to cogeneration.

Let me leave you with what I think the solar message for you should be, and that is: if we can do what I believe we are on the path to doing, and if we can come up with equipment that is reliable, that satisfies customer requirements, and if we can achieve our cost goals at the same time, then solar energy will represent a stabilizing influence in our energy supply situation, which could be very welcome at this point. Its fuel costs won't escalate, and probably the sun will continue to shine, and to be blunt, environmentalists will not hold it up and they probably will not shut it down. There are other concerns in this society that probably will attract their attention.

THE NATIONAL HYDROPOWER STUDY

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By extracting energy from falling water hydroelectric power has been a primary source of power and energy in the U.S. for over 100 years. The scarcity and skyrocketing price of liquid fuels motivated Congress to sponsor a comprehensive study to examine the nation's hydropower resources. This study, the National Hydropower Study (NHS), was designed to develop an inventory of existing and potential hydroelectric power sites, to estimate the magnitude and regional distribution of demand for hydropower, to prepare a plan for future development based on the supply and demand for hydropower and an assessment of social, economic, environmental and institutional factors, and to suggest appropriate Federal policies, strategies and procedures to encourage the development of hydropower resources if warranted.

SETTING Electric power now accounts for about 30% of the nation's total energy consumption, about 25 quadrillion BTU's. Coal generates 44% of this total, petroleum 17%, natural gas 14%, nuclear power 13% and hydropower 13%.

Hydroelectric power projects have an installed capacity of about 73,000 MW, including pumped storage. This amount of capacity produces about 280 billion KWhr/year or 3 quads. Hydropower accounts for about 40% of total electric capacity in the Western States, 10% in the Southeast, 15% in New England and less than 5% in other regions of the country.

Hydropower is used to supply base load, intermediate load, and peaking power to meet varying electric loads. Since hydropower can respond to fluctuating loads quickly and at less expense than thermal sources, the trend is to use hydropower during peak power demand periods whenever possible. Despite its small percentage of the electric power source mix, hydropower is an important ingredient for the efficient and reliable operation of electric power systems, and will continue to be important.

DEMAND Forecasts of future electric power demand vary widely, reflecting a high degree of uncertainty about future costs of electric energy production and the associated role of electricity in the energy marketplace. Many small hydropower projects are insensitive to the demand for electricity over wide ranges. The output from small plants can be absorbed almost unnoticed by a utility grid. If a hydropower plant is cost effective as a fuel saver it will probably be built without regard to future demand growth.

Hydropower projects are sensitive to the shape of the load curve of a region as well as the absolute growth in peak power demand. The value of hydropower increases if it can meet peak loads.

For the purposes of the NHS, we used a median electric peak demand growth level based on an examination of an array of existing forecasts. A forecast for the future shape of load curves for each region of the county was developed. The demand and load shape forecasts were used to determine the need for and value of potential hydropower projects.

SUPPLY The NHS approach to supply estimation was to use physical data on existing dams, other water resource structures and previously studied undeveloped sites to compute capacity, energy, cost of development, and value of output at each dam or dam site using generalized computer models and algorithms. Additional site information was collected to screen economic sites for environmental and institutional acceptability.

Although the final results of the site inventory and evaluation work are still being compiled, preliminary estimates show that the expected hydropower development over the next 20 years will involve between 3000-6000 sites,provide 35000-68000 MW of capacity, and generate 85-160 billion KWhr of electricity annually.

FACTORS AFFECTING HYDROPOWER DEVELOPMENT The term "factor" is defined as any social, economic, environmental or institutional element that currently affects the future development and use of hydroelectric power.

ECONOMIC The relative economic cost of hydropower versus other generating sources is a primary factor. The least cost option, all other factors being equal, will be built. However, the true value of a planned hydropower project is elusive. The alternative cost of a thermal alternative is the surrogate for the value of hydroelectric power. Oftentimes, a complete analysis of a regional electric production system is needed to verify the true alternative cost of a thermal alternative to a hydropower project. General models are available for this purpose.

External economies and diseconomies are other important factors. As an example, nuclear waste disposal and air pollution effects from fossilfuel combustion are recognized cost element for alternative sources yet these costs are not usually included in economic evaluation. The extent to which these costs are eventually accounted for will affect the rate of future hydropower development.

Another important factor involves the multiple-use aspect of reservoir storage and streamflow. Specific regions of the country are already overtaxing their water resources and prospects for reversing the situation are dim. Any estimates of hydro's future must consider the compromise that must be made to accommodate other water uses. Water rights battles will be a by-product of any future hydropower scenario.

ENVIRONMENTAL Environmental factors have both positive and negative aspects with regard to hydropower. As a general rule hydropower is the most environmental benign of all conventional means of generating electric power,especially when facilities are added to existing structures. On the negative side, utilization of undeveloped sites require the flooding of a large section of natural streams.

OTHER FACTORS There are other hydro characteristics that affect it's future. Hydropower is a renewable resource constantly replenished by the hydrologic cycle powered by the sun. As such, hydropower production is impervious to depleting fuel levels and soaring costs. Hydropower is a highly efficient means of producing electricity. About 90% of the available energy in falling water is converted to electrical energy with modern turbines and generators. Coupled with this high efficiency is an equally impressive durability and reliability. Hydropower is extremely useful for electric utilities, because it can be started up very quickly and provides ready spinning reserve to meet load changes. Also, hydropower plants, particularly pumped storage, are the most economically large scale storage medium for electric energy available today.

Conversely, since hydro production depends on streamflow, hydropower is intermittent unless large volumes of storage are made available. The instantaneous availability of hydropower can not be determined except by probabalistic methods. Also, as during the long term drought which recently occurred in the West, hydropower production can be reduced drastically, even with large-scale storage.

A longer term factor with hydro relates to the structures and reservoirs. Dams may become safety hazards if not maintained. Also, reservoirs behind hydropower dams will enventually fill with silt reducing the effectiveness of the hydro site.

The process by which private and federal hydropower projects are initiated can be a significant barrier to future development. The FERC has achieved considerable progress toward streamlining the arduous licensing process. A number of State governments have reduced unnecessary red tape. Federal agencies are subject to a complicated and time-consuming process for implementing hydropower projects, and until changes are initiated by Congress, the addition of new Federal hydropower projects, even those at existing dams, will be slow coming.

SECTION 3

BIOMASS

BIOMASS

Program Chairman: *Martin Scholl,* The MITRE Corporation
DOE Advisor: *Beverly Berger*
Overview Presentation: Tuesday, December 9, 11:00 A.M.

"Biomass Systems: A Strategic Overview" 2-19
Leslie S. Levine, DOE

SESSION I: Tuesday A.M.
Overview

"Biomass: The Western Hemisphere's Non-Commercial Fuel" . . . . . *
Vladimir Yackovlev, Organization of American States
"Advanced Biomass Concepts" 3-1
Clayton Smith, Solar Energy Research Institute
"DOE and the Alcohol Program – Present and Future" . . . . . *
Bert Greenglass, DOE

SESSION II: Tuesday P.M.
Alcohol Fuels

"A Technology Assessment of Terrestrial Biomass Energy Systems" 3-3
R. Channing Johnson, The MITRE Corporation
"Gasohol in the Transportation Sector: Today and in the Future" 3-5
James P. Jolly, Texaco Inc.
"Ethanol Production from Terrestrial Biomass" 3-7
F. J. Edeskuty and G. R. Thayer, Los Alamos Scientific Laboratory
"Methanol from Wood" . . . . . *
Jack Rooker, Davis, McKee Corp.
"Alcohol Fuels in Brazil" . . . . . *
Lourival Carmo Monico, Secretaria de Technologia Industrial, Brazilia

SESSION III: Wednesday A.M.
Residential and Farm Use of Biomass

"Long-Term Economic Prospects and Markets for Residential Use of Biomass" 3-9
Roger H. Bezdek, U.S. Department of the Treasury
"Planning for Residential Use of Wood" . . . . . *
Robert Hemphill, TVA
"Presently Expanding Residential Use of Wood Fuel in New England" 3-11
Frederic A. Hills, Northeast Solar Energy Center
"Health and Environmental Effects of Residential Wood Heat" 3-13
C. C. Travis, H. R. Meyer, and C. S. Dudney, Oak Ridge National Laboratory
"Fuel from Farms: Introduction to Ethanol Production" . . . . . *
V. Daniel Hunt, TRW, Inc.
"Integrated Farm Energy Systems: Near Term" 3-15
James L. Butler, USDA, SEA Southern Agricultural Energy Center

SESSION IV: Wednesday P.M.
Utility and Industrial Use of Biomass

"The Use of Biomass for Electrical Generation and Cogeneration: Bonneville Power Administration's Experience" 3-18
Sterling Munro, Bonneville Power Administration

*Abstract not available for printing in Conference Proceedings

Session IV (continued)

"Biomass Use for Island Utilities" 3-20
Julio Negroni, Center for Energy and Environmental Research, Puerto Rico
"Parameter for Planning Utility and Industrial Use of Biomass" ..... *
Donald Pingrey, Northwest Pacific Corporation
"Sacramento Gasification Project" ..... *
Howard Masson and Wes Toy, Acurex Corporation
"Promoting Biomass Conversion to Energy in California" 3-22
Joseph F. Silvey, Envirosphere Company
"Industrial Use of Biomass Resources in New England" ..... *
Gordon L. Deane, New England Regional Commission

SESSION V: Thursday A.M.
Biomass Energy in Agra-Business

"Integrated Energy Systems for the Sugar Industry" 3-24
Charles M. Kinoshita, Hawaiian Sugar Planters' Association, and *Edward J. Lui,* Pacific Resources Inc.
"Biomass Energy Use in the Sugar Industry" ..... *
Willard Eller, Hawaiian Commercial and Sugar Company
"Combustion Technology for Industry and Agra-Business" 3-26
Harold M. Johnson, Farm Show Magazine
"A Developing Hawaiian Energy Plantation" 3-28
Jerry E. Allen, C. Brewer and Company, Limited

SESSION VI: Thursday P.M.
Longer-Term Biomass Options

"Latex-Producing Plants as a Source of High Energy Liquid Fuels" 3-30
John W. Otvos, Esther K. Nemethy, and Melvin Calvin, Lawrence Berkeley Laboratory
"Terrestrial Energy Farms" 3-32
Robert E. Inman, Solar Energy Research Institute
"Genetic Engineering for Greater Energy Efficiency in Sugarcane" 3-34
Thomas L. Tew, Hawaiian Sugar Planters' Association
"Marine Biomass Energy Systems for the Production of Methane" 3-36
A. Flowers and J. R. Frank, Gas Research Institute
"Tropical Grasses" 3-38
A. G. Alexander, M. Garcia, and W. Allison, Center for Energy and Environment Research, Puerto Rico

ADVANCED BIOMASS CONCEPTS

Clayton S. Smith
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During preceeding sessions other speakers have discussed the supply of biomass, current applications and some projected advances. Hopefully, this paper will anticipate some opportunities not addressed by other presentors. Fortunately, its position on the program allows the opportunity for a last word. The author therefore reserves the right to tailor at least a portion of his presentation to complement and emphasize prior information.

Biomass has been shown to have significant potential as a renewable energy resource. To those who have explored the possibilities, the incredible diversity of the technology and its opportunities seem to give assurance that biomass indeed will contribute to our energy future. As a framework to discuss some advanced concepts, we will consider biomass as a supply or a converter of solar energy, with selected conversion options and some opportunities for its use or application.

Perhaps the most intriguing and exciting opportunities for significant improvement in production of biomass lies with microorganisms. Various algae are capable of very high photosynthetic efficiencies. Many of these organisms can be coaxed into producing large quantities of lipids of all sorts. Generally, these organisms grow in brackish or saline waters. Much of the necessary technology may be adoptable from demonstrated systems such as solar salt production. Some microorganisms can produce a relatively pure hydrogen. Present efficiencies are low, but other benefits include highly efficient water treatment. Unusual terrestrial plants exist which might be grown on plantations, such as the rubber tree, and periodically harvested for their unique energy components. If one considers a penny saved as a penny earned, then the development of legume-like ability to fix atmospheric nitrogen in other food plants is the development of biomass energy.

The conversion of biomass to useful energy compounds is an area of significant potential for advancement. Lignocellulose and other biomass stores not only solar energy but also atmospheric carbon. Conversion of carbohydrates to high energy fuels results in the immediate return of substantial CO_2 without producing a useful fuel. Thus, anaerobic digestion to biogas ($CH_4 + CO_2$) fermentation to fuel ($C_2H_5OH + CO_2$), thermal conversion to olefins ($C_2H_4 + CO_2$) do not make full use of this carbon. Conversion methods which provide for biomass reduction can substantially increase the yield of storable liquid fuels and make use of other renewable resources such as hydroelectric and solar produced hydrogen. Electrochemistry is a key to such developments. Biotechnology as applied to biomass conversion opens a new frontier. Development of fermentative organisms operating at high concentrations and high temperatures to produce not only ethanol but a wide variety of petrochemical replacements is imminent. Dramatic improvements in the ancient art of alcohol production are in development. Direct production of electricity using components of cells immobilized on electrodes has been demonstrated, albeit at very low efficiencies. Theoretically, such devices can exceed the limits for solid state photovoltaic devices. Man-made analogs are being constructed.

Applications advances are not being ignored. Derivatives of biomass can, and are, likely to displace petrochemicals in several areas. A turning of the tables

is only just considering what polyesters have done to rayon and cellulose acetate. The opportunity to tailor engines to use alcohols and other biomass-derived fuels at optimum efficiency is great. SERI is building and testing a methanol fueled automotive system which provides twice the thermodynamic efficiency of the standard engine system. Other advanced hybrids are possible, for example, an alcohol fuel cell - electric car with the advantage of great range and electric car performance.

The technologies and technical objectives clustered around the biomass banner offer a multitude of truly innovative advanced concepts.

A TECHNOLOGY ASSESSMENT OF TERRESTRIAL BIOMASS ENERGY SYSTEMS

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The MITRE Corporation has completed a technology assessment of terrestrial biomass energy systems. The assessment was performed under a grant from the National Science Foundation. The focus was on the impacts that will follow from a substantial use of biomass for energy and on the policy implications of these impacts.

Four specific systems for the production, conversion and end-use of energy from biomass were chosen for detailed assessment. They are:

- Residential heating with wood;
- The use of wood from the traditional forest for industrial steam and cogenerated electricity;
- The large-scale production and use of gasohol from corn;
- Methanol transportation fuel from wood from intensive silvilcultural farms.

These particular systems were selected because, first of all, they were evaluated as having good potential for making a significant contribution to energy supply between 1990 and 2000. Second, as a set, these systems are believed to illustrate the impacts of producing, converting and using biomass for energy.

The impacts of the four systems were traced in some detail. The assessment team then generalized from these four studies to the broader implications of energy from biomass. The principal conclusions follow.

The production of biomass varies from year to year. This is particularly true for an annual row crop like corn, less true for a tree plantation. Against this variability of supply, a higher level and steady demand will be placed. Unless some combination of land setasides and harvest carry-over is practiced to balance out yearly supply and demand, the swings in price will affect not only the food and fiber sectors, but the viability of energy projects.

The lowest cost biomass production is usually on the highest quality land. Increased competition for prime crop and woodland will drive up the price of land and increase the fixed costs of farming and forestry. This will tend to transfer wealth from consumers to landowners.

Increased use of marginal land will increase the variability of supply of food, fiber and energy and increase the potential for damage to the land. This is particularly true if energy programs reward the use of the land rather than the care for the land.

The land intensiveness of biomass energy can be reduced by increasing the productivity per acre and by increasing the conversion of biomass carbon to usable energy. Productivity of forestland, particularly privately-owned non-industrial forestland, can be increased by rewarding the use of modern forest management practices. Intensive silvicultural farms will further increase productivity. The use of distillation by-products as high protein feed supplements rather than for their energy value on feedlots reduces the land intensiveness of gasohol. Hybrid methanol systems that combine hydrogen-rich synthesis gas from natural gas with hydrogen-poor synthesis gas from biomass avoid the steam-reforming step and increase the conversion of biomass carbon to transportation fuel. Airtight stoves

are preferred to fireplaces or Franklin stoves.

The growing, harvesting and transporting of biomass is labor intensive compared to coal, oil or nuclear energy. Biomass conversion facilities are relatively small by industrial standards. The labor impacts of a biomass program should enhance rural and small town employment and are not expected to create the boom towns that will come with oil shale and coal conversion programs. Occupational injuries and deaths will increase. Agriculture and forestry are among the most hazardous occupations.

It is believed, but not at all certain, that biomass energy systems are preferred environmentally to energy systems based on coal, oil shale or nuclear power. Residential heating with wood is dirty, hard to improve at reasonable cost, and hard to control except by prohibition. Methanol is preferred to gasoline, and especially leaded or high octane gasoline. But it also introduces a new set of hazards and pollutants with undetermined health effects. And how does one compare, system against system, the environmental impacts of a synfuel from oil shale with a methanol from a silvicultural farm?

The agricultural sector and the forest products industries have been users of energy. As they become producers of energy, they will come into closer relationships with the big energy companies. A number of joint ventures in alcohol have recently been announced between petroleum companies and the large food-processors. Likewise the Department of Agriculture and the Department of Energy will find overlapping concerns. These two departments have quite different mandates, constituencies, and ways of doing business. Likewise, landowners may find themselves under increasing regulations as the land and the products from the land are increasingly seen as a scarce national resource.

While it is believed that a substantial number of quads of energy can be produced from biomass without reducing the output of food and fiber, the use of basic foods for energy may become a highly emotional issue. Population in the LDC's will rise rapidly in the next two decades and the capacity to produce food may falter, in part due to the higher cost of energy.

GASOHOL IN THE TRANSPORTATION SECTOR: TODAY AND IN THE FUTURE

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Texaco sees gasohol as an extender of the nation's motor fuel supplies, particularly on a regional basis where the extender ingredient, ethanol, is in ample supply. However, despite its importance as an extender, its overall contribution is relatively minor. For example, Texaco Lead-Free Gasohol represents about 1.0% of the company's motor fuel sales as of mid-1980. Thus, as the leading U.S. gasohol marketer, Texaco sells only about 0.1% of its motor fuel as ethanol. Gasohol will serve as an extender of gasoline during the interim period while new sources of liquid fuels are being developed as long-term solutions. Texaco is working on a number of alternate energy sources, of which gasohol represents only one. We believe that synthetic fuels, including methanol, from coal, along with refined fuels from shale oil and tar sands, and solar, nuclear and geothermal energy each has a role to play in our energy future.

Marketing experience to date has shown good acceptance for gasohol in all areas of introduction. Performance of gasohol in the field has generally been good, with few operational problems reported. An octane increase of two to three numbers is provided by the addition of 10% ethanol to unleaded regular gasoline, resulting in a substantially higher number of automobiles being satisfied with regard to anti-knock requirements. While reports of fuel economy have varied from substantial increases to substantial decreases, the long-term effect is expected to reflect the lower energy content of the ethanol component and give slightly lower volumetric fuel economy for gasohol.

Testing to firm-up emission data is continuing, but no significant problems are expected in this area. Minor materials compatability problems could be experienced in older cars, but should pose no problem in newer vehicles designed to use gasohol. Filter plugging problems which were expected to result from the tendency of ethanol to loosen fuel system deposits are minimal.

Texaco has moved toward increasing the fuel-grade ethanol supply by entering into a partnership with CPC International Inc. to modify CPC's existing coal-fired corn wet milling plant in Pekin, Illinois, for ethanol manufacture. This plant will produce 60 million gallons per year of ethanol, along with the normal by-products of corn wet milling, starting about the end of 1981. Based on the use of coal as a primary fuel source, the net gain in valuable liquid fuel is positive.

The desirability of producing ethanol as a motor fuel hinges upon whether there results a net gain of energy in a usable form. Texaco believes that if a non-critical source of energy such as coal or agricultural waste is used as the fuel source, the production of ethanol as a liquid motor fuel makes good technical and economic sense.

In order to put the ethanol energy balance in perspective, a comparison of output energy recovered versus input energy in ethanol manufacture versus other common energy conversions is shown in the tabulation below. These data show that the ethanol energy balance is no less favorable than those for commercial processes for upgrading other fuels.

	BTU PRODUCED/BTU CONSUMED
Ethanol from Grain	0.8/1
Gasoline from Crude	0.7/1
Gasoline from Coal or Shale	0.5/1
Electricity from Coal	0.3/1

At the present, governmental incentives, both federal and state, have a major impact on the commercial viability of gasohol. The federal incentives of 10% Investment Tax Credit and 10% Energy Tax Credit encourage construction of new facilities for ethanol production. The elimination of the Federal Excise Tax (4¢/gallon) on gasohol makes the fuel more competitive in the marketplace. As of mid-year, twenty-two states had reduced or eliminated the motor fuel tax on gasohol, five had exempted gasohol from the sales and use tax and several others had miscellaneous tax incentives. A large number of others have pending legislation for various types of tax relief.

The future impact of gasohol from biomass-based ethanol as a motor fuel will depend upon the development of technology to enable use of raw materials other than food crops, the speed with which other alternate fuels are developed and commercialized and upon energy policy of government at all levels.

ETHANOL PRODUCTION FROM TERRESTRIAL BIOMASS

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Recently ethanol has received much publicity concerning its use as an automotive fuel. Although capable of being used undiluted, ethanol can be added to gasoline (10% ethanol) resulting in a fuel requiring no modification of a vehicle from its original design for gasoline fuel. Furthermore the ethanol contributes to an increased octane rating of the fuel. The higher heating value of ethanol is 84,600 Btu/gal compared to 124,000 Btu/gal for gasoline. In spite of this lower energy content, reported fuel efficiencies as well as emissions seem to be about the same for either gasohol or gasoline. However, ethanol produced from hydrocarbons also finds use in the chemical process industries and some crude oil imports could also be avoided by producing this ethanol from biomass. To replace the total U.S. gasoline consumption with gasohol (10% ethanol) would require the annual production of about 10 billion gallons of ethanol (thus reducing petroleum imports by about 20%). The U.S. chemical requirements for ethanol are about 250 million gal/year.

Ethanol can be produced from many different biomass sources. From sugars it can be produced directly by fermentation which takes about 30 hours at about 100°F, and results in an ethanol concentration of up to 12%. Production from starch (e.g., corn) requires the additional step of breaking up the longer starch molecules by enzymes to form fermentable sugar. If cellulose is to be used as the feedstock, the breaking down of this molecule is even more difficult requiring either an acid hydrolysis or a more powerful enzyme. The production of ethanol from either sugar or starch is already developed, while production from cellulose is in the development stage. In all cases the subsequent separation of the ethanol must be done (usually by distillation) with the additional complication of the constant boiling mixture that forms at 95% ethanol (190 proof). Thus, the final degree of separation requires an azeotropic distillation or some other expedient such as molecular sieve adsorption to produce the 100% (200 proof) ethanol required for gasohol use.

The energy balance computed for ethanol production varies widely depending upon the actual process and must take into account the energy used in farming as well as the process energy. The farming energy has been estimated over wide limits from 40,000 to 100,000 Btu/gal of ethanol produced whereas process energy estimates have varied all the way from 20,000 to 40,000 Btu/gal. Comparing the sum of these estimates to the combustion energy, it can be seen that the energy balance for ethanol production can show anything from a large loss to a small gain. A thorough review of this subject was made by the Alcohol Fuels Policy Review which reached the conclusion that about a 5% gain would be achieved in using current technology and taking the appropriate credit for the distiller's grain. While this energy balance is not very favorable, it should be mentioned that further process improvements are still possible and if nonpetroleum energy sources can be used, this is still an effective way of replacing imported energy with domestic energy.

The capital costs of ethanol facilities also vary considerably. For larger facilities (10^7 gal/year or larger), typical estimates run from $2 to $3 per annual gallon of production. For smaller (farm size) facilities the estimates run between $1 to $2 per annual gallon of production. This is more understandable when

one considers that the smaller plants are for the production of 95% (190 proof) instead of 100% ethanol, and that the smaller plant does not usually include boiler feed water or waste water treatment, and that no land costs are considered. Using available estimates for capital investment and for operating costs, we have made average life-cycle costs for the production of ethanol for large facilities of 10^7 gal/year and farm-size units 0.36×10^6 gal/year.

The life-cycle costs for the 10-million gal/year plant with coal as a fuel source was based on plant costs given by Katzen. A life-cycle cost of a gallon of ethanol was calculated to be $1.71, in 1980 dollars using $2.50/bu corn and $35/ton coal. The calculations for the life-cycle costs were performed using a code developed at LASL to calculate levelized life-cycle costs for various technologies. The principles behind levelized life-cycle costs are that the income over the lifetime of a project must equal the project expenses (including a 20% return on investment). The 10 million gal/year plant was assumed to be financed with 70% equity, 30% debt with a 9% interest rate and the debt paid in a fixed payment schedule. The plant lifetime was assumed to be 20 years and a 6% inflation rate over this time period was assumed. The yearly recurring costs were escalated at a rate at 2% above inflation for labor. Corn and DDG prices were assumed to increase at the rate of inflation.

A similar calculation for a 50-million gal/year ethanol plant using sugar cane gave an estimated levelized life-cycle cost of $1.77/gal ethanol. This assumed a sugar cane cost of $20/ton and year round operation with no long term storage facilities on site. Bagasse was used for fuel and any excess steam capacity was used to produce electricity which was sold for 5¢/kWh. In this case the price of sugar cane was escalated at a rate 2% above inflation.

For a smaller, farm-sized unit producing 360,000 gal/year, capital equipment expenditures and operating costs were taken from the U.S. Department of Agriculture. For an on-farm corn price of $2.50/bushel and a by-product credit of 4¢/pound for distillers grain (with 65% water content and for local distribution), the resulting life-cycle cost for 190-proof ethanol was $1.36/gal. Doubling the capital investment increased this cost to $1.49/gal and an increase in corn feedstock price to $3.00 resulted in a cost of $1.56/gal. A decrease of process energy requirement to 20,000 Btu/gal resulted in a life-cycle cost of $1.31/gal. The apparent cost discrepancy between the large and farm-sized facilities is more understandable when one recalls that the latter's product is 95% alcohol and that the capital investment is also smaller, as explained earlier.

An ethanol production facility has the potential of producing several by-products or alternate products. The ability to vary the production emphasis will be important to farm-size facilities. The current energy ratio is, in general, not sufficiently favorable to assist greatly in easing our energy problems when imported fuels (diesel, gasoline) are the energy source. However, if domestic fuels (solar, coal) can be used, then ethanol produced from biomass can be an important addition to our energy supplies. A number of process improvements are being studied and promise dramatic improvements in the overall energy balance. At present gasohol is economically competitive because of the tax incentives which result in artificially low fuel prices. Although this tax relief should not be continued indefinitely, it must also be remembered that gasoline prices are also artificially low so that it would be better to compare ethanol prices with the much higher cost of gasoline produced from the imported oil. It is generally believed that in the long term ethanol cannot compete economically with methanol, however, there will always be a market for ethanol in the chemical process industries.

LONG-TERM ECONOMIC PROSPECTS AND MARKETS FOR RESIDENTIAL USE OF BIOMASS

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This paper reviews the economic and marketing prospects for the use of biomass energy in the U.S. through the year 2000, focusing on the potential in the residential market. We analyze the market for biomass technologies in two categories: wood combustion technologies and synthetic fuels from biomass.

Wood Combustion Technology

Wood is a versatile energy resource that has a wide range of direct application in all market sectors of the economy. Wood combustion technologies currently provide more than 1.5 quads of energy--1.1 quads in industrial steam production and 0.4 quad in residential units. Industrial use is almost exclusively within the pulp and paper industries.

The use of wood for energy is expected to increase by 1985 to 2.5 quads, approximately 3% of the projected national energy consumption and by the year 2000 to almost 4.5 quads. Meeting the 1985 goal will require the installation of significant numbers of wood combustion units. This would include an additional 3 million residential units, 150 industrial steam units, 60 industrial cogeneration units and low BTU gassification units, and 30 electric utility systems.

Wood combustion equipment for most applications is commercially available. Approximately 8 million wood stoves and fireplaces are currently in use in the U.S., although only about 250,000 housing units use wood as a primary fuel. The primary technological needs are for improvement of units inserted in fireplaces to reduce creosote build-up, improvement of advance design units to further increase efficiency, and related technological improvements.

A large potential for wood combustion is the replacement of existing gas- or oil-fired boilers with wood systems. This application is especially attractive in regions subject to gas curtailment or relatively high fuel oil cost where surplus wood is available.

Use of wood energy is limited by four barriers. First, in most regions, the greatest restriction to the development of a market for wood combustion technologies is the assurance of an adequate supply of wood resources. Potential users will be reluctant to commit significant funding to a technology if they anticipate resource supply problems. Second, environmental issues constitute a major uncertainty in the use of wood combustion technology, for wood combustion tends to produce large quantities of particulates, and strict enforcement of environmental regulations could pose significant barriers to its increased use. Third, the total capital investment required to meet the 1985 goal alone for wood combustion is over $30 billion. Finally, the limited experience with wood combustion outside the forest products industry retards market penetration of this technology.

Synthetic Fuels from Biomass

In recent years, something over 25% of the energy consumed in the U.S. was used in the transportation sector with 97% of the energy derived from oil. Thus, production of synthetic fuels from biomass would directly displace U.S. use of oil and help alleviate domestic production shortages of liquid fuels. Estimates of the potential for supplying synthetic fuels from biomass differ significantly. However, given the recent escalations in petroleum prices, the cost of producing alcohols from biomass is likely to be equal to or less then the cost of petroleum derived fuels in the very near future.

In his energy message last July, the President indicated a 1990 goal of displacing 100,000 barrels per day of oil by producing fuels from biomass. Such a program will require the installation of at least 26 fermentation plants using corn, two plants for hydrolysis and fermentation of agricultural residues, two plants for conversion of usable solid waste, and two methanol plants using wood. Alternatively, this goal can be met by the installation of 75,000 small on-farm systems, each producing no more than 20,000 gallons of ethanol per year.

Synthetic biomass fuels include methanol and gasoline produced from wood and municipal solid waste as well as ethanol derived from crops, crop residues, and municipal solid wastes. The technology for producing ethanol from grain is well developed, and commercial production has been escalating in recent years to meet consumer demands for gasohol. The process for producing ethanol and methanol from other biomass resources is fairly well advanced although there are currently few commercial production facilities.

There is presently a market for liquid fuels from renewable resources as evidenced by the large increases in sales of gasohol in recent years. Over the long run, however, the market for alcohols from biomass resources will be limited by several factors. First of all, the long-term limitation on the production of alcohol from biomass residues is the availability of agricultural wood residues. Second, engine performance with alcohol gasoline blends is uncertain. Third, optimization of gas production for alcohol and gasoline blends will require reformulation of refinery processes. Finally, to meet the 1990 goal, no less than $2.2 billion of capital will be required.

Thus, the major markets for biomass over the next 20 years will be industrial process heat, electric utilities, and synthetic fuels. The residential uses of biomass, almost exclusively wood-burning stoves and fireplaces, will contribute about a half a quad of the U.S. energy supply in the year 2000, or something less than one-half of 1%. Even under optimistic conditions, direct residential uses of biomass cannot be looked upon as a significant solution to the energy crisis until well into the 21st Century.

PRESENTLY EXPANDING RESIDENTIAL USE OF WOOD FUEL IN NEW ENGLAND

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Since the oil embargo of 1973, the use of wood fuel has increased in regions of the U.S. where home heating is a necessity. This is especially true of the Northeast where home heating oil costs have more than doubled in the past three years. Estimates are that nearly three million cords of wood were burned in 1.5 million New England homes during the winter of 1978 - 1979, equivalent to 226 million gallons of #2 heating oil.

As wood fuel has become more widely used, surveys and analyses have been undertaken. Excitement over a potential "solution" to New England's oil dependence and high energy costs has found opposing forces in environmental concerns. A highly dynamic situation now exists, involving diverse interests of consumers, landowners, manufacturers, fuel suppliers, government and the community.

The six-state region contains 66,608 square miles and 12.7 million residents--as many people as Texas in one-quarter the area. The population ranges from densely urban and suburban in southern Connecticut and eastern Massachusetts to rural in all states. Much land is inaccessible and wild, especially in northern Maine, New Hampshire and Vermont. Nearly 80 percent of the region is forested but most is not under formal forest management. From 56 to 85 percent of the total area of each state is classified as commercial forest land, suggesting a vast untapped energy resource. While upwards of 87 percent of the forest land in each state is privately held, only one-quarter of the total is owned by paper, pulp, and lumber companies. Thus, a fertile environment exists for wood fuel entrepreneurship on both an industrial and commercial scale and a local, residential supplier basis.

New England's energy situation has worsened rapidly since 1973. Eighty percent of the region's energy requirements are derived from oil--nearly twice the national average. While foreign imports account for only 39 percent of U.S. oil consumption, 79 percent of the oil consumed in New England is from foreign sources. This situation places New England in a particularly vulnerable position. Because of this, each Governor has established a ten-year goal to reduce oil dependence by 20 percent. New England energy costs are 26 percent higher than the national average. The region produces no fossil fuels and being remote from domestic supplies, fuel transport costs are a major factor. Nuclear power has helped to protect the region from an even greater dependence on oil--it now provides one-third of the electric power used--but expansion of nuclear capacity has virtually stopped. Two regional energy alternatives found in abundance--wood and hydroelectric--have not received the massive government financial incentives extended to fossil fuels and nuclear power.

It has been estimated that New England could harvest as much as two billion cubic feet of wood annually to the year 2000. An increase in woodburning of only 10 percent per year could result in 250,000 bbl's/day oil equivalent by the year 2000 or one-eighth of the total estimated demand for the region.

Though home heating with wood has been common in rural areas, we now find more than 24 percent of New England homes have a woodstove or furnace. In a Maine study,

46 percent of homeowners burned a total of 468,000 cords of wood during the winter of 1977 - 1978. In 1977, 52 percent of New Hampshire households burned wood and more than two-thirds of these cut all or part of the 300,000 cords used. Between 1977 and 1978, the proportion of Vermont households burning wood rose from one-half to two-thirds and an earlier survey showed over 60 percent of woodstoves in use were installed in the three years following the 1973 oil embargo. Studies in Massachusetts, Rhode Island, and Connecticut show a surprising 57 percent of the 2.85 million cords burned in New England in 1978 - 1979 were consumed in those states, indicating a wood heating trend in more populous, affluent areas. These surveys also found cordwood prices ranging from $40 to $140 per cord and increased demand has pushed prices even higher over the past year. Along with price, wood quality and cord "size" vary considerably, prompting some states to examine the need for standards.

Environmental concerns have grown nearly as rapidly as woodstove sales. Though proven timberstand management methods exist, potential overcutting, erosion and nutrient depletion have prompted resistance to clearcutting and whole tree chipping. Adverse air quality effects are being felt, especially in more densely populated areas. As homeowners have moved to airtight stoves for improved thermal efficiency, incomplete combustion has caused increased emissions. Studies indicate that air quality problems are related to a number of factors difficult to control: meteorological conditions, local terrain, number and location of woodburning homes, quality of fuel and combustion efficiency. These suggest localized rather than general, widespread problems will occur in the near term.

In summary, the various studies indicate New England is experiencing an exponential rise in the use of wood fuel for home heating, especially in more densely populated areas. As heating oil prices escalate, homeowners are attracted by the small capital investment for a woodstove and the rapid payback possible. Consumers are becoming better informed, more knowledgeable and increasingly selective regarding equipment. Protection of forest resources and air quality are growing concerns to environment, community and governmental groups.

Though much interest and activity has been stimulated, there is a great need for region-wide coordination of present activity and future plans. Residential heating equipment needs improvement; central heating systems are needed to supplant woodstoves. Fuelwood distribution and retailing networks similar to existing oil delivery systems are needed. Most important is the need for a concerted effort toward an environmentally and economically sound use of forest resources--an approach that makes fuelwood harvesting an integral point of an extensive timberstand improvement and harvesting movement in New England.

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A complete list of references will be available at the Conference.

HEALTH AND ENVIRONMENTAL EFFECTS OF RESIDENTIAL WOOD HEAT

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Increasing use of efficient high-temperature wood burning stoves as primary or secondary heat sources in urban residences poses a unique potential threat to the health of a large segment of the United States population. Although the need for additional study is apparent, it is evident that: 1) under conditions of meteorological inversion and low wind speed, concentrations of particulates from wood combustion can exceed ambient air quality standards, and 2) a number of toxic chemicals, including the potent carcinogens benzo(a)pyrene(BaP), dibenz(a,h) anthracene and benz(a)anthracene may be present in significant quantities in flue gases. While no evidence exists to directly link the presence of such materials in the atmosphere with cancers in man, prudence suggests further study of the problem.

Gross energy consumption in the United States is projected at 160 quadrillion Btu (quads) by the year 2000 (Ref. 2), more than a two fold increase as compared to U.S. consumption in 1974. As costs of fossil fuels increase in response to declining supply, alternate sources of home heat, particulary woodburning stoves, will become increasingly attractive. As an indication of this trend, residential use of wood as a primary fuel increased by 50% from 1973 to 1976, to a total of 9,000,000 U.S. homes. Some 450,000 new homes with fireplaces were built in 1975, and about 550,000 wood-burning stoves were shipped by manufacturers. While this trend is welcomed from the standpoint of reducing U.S. dependence on foreign oil, it may have significant health and environmental impacts. A recent study of a residential area in Portland, Oregon found that residential wood combustion accounted for between 36 and 49 percent of total respirable air particulates.[3] A study in Vail, Colorado estimated that residential wood combustion could contribute up to 0.64 tons of particulates per day to the valley's air pollution levels[4] (Vail is currently limiting residental wood burning).

The most recent and detailed characterization of emissions from fireplaces and wood stoves was sponsored by the Environmental Protection Agency.[1] This study (which identified only 15% of the condensable emissions) found that smoke from woodburning stoves and fireplaces contained 17 priority pollutants, 14 known carcinogens, 4 cocarcinogens, and 6 cilia toxic agents. The Ames test, applied to 24 emissions samples from stoves and fireplaces, indicated mutagenic activity in all cases. Ash residues, in contrast, were found to be nontoxic.

While slow combustion of wood in "air-tight" stoves is attractive from a thermal-efficiency standpoint, reduced air flows and lower combustion temperatures result in enhanced emissions of carbon monoxide and polycyclic organic material (POM).

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The EPA study found that emissions of carbon monoxide and POM are an order of magnitude higher for air-tight wood stoves than for fireplaces. (Condensible organics and particulate matter were produced in roughly equal quantities and NO_x emissions were found to be from 2-6 times higher for the open fireplace configuration.) Emission rates, in grams of pollutant emitted per kilogram of wood burned are summarized below: (Adapted from Ref. 1)

	Particulate Matter	Condensable Organics	NOx	CO	Polycyclic Organic Matter (POM)
Open Fireplace	2.4	6.7	1.9	22	0.031
Airtight stove	4.1	6.0	0.6	180	0.29

The EPA report notes that, since the important woodburner pollutants are related to incomplete (oxygen-reduced) combustion, such variables as fuel charge, fuel arrangement and air-to-fuel ratio may affect POM and CO output.

Emissions of POM from residential wood combustion are significant and appear to be much larger per unit of available heat than any other residential heat source:

POM Emission Factors From Residential Sources

	pg/J
Wood (Airtight Stove)	15,000[a]
Bituminous Coal	1,900[b]
Oil	1.0[b]
Gas	4.2[b]

[a]Ref 1 , [b]Ref 5

Since several polycyclic organics are known to be strong animal carcinogins, their presence in flue gas could pose health problems in regions of high residential wood use.

Given rapidly increasing U.S. utilization of residential woodburners, and quantitative evidence that high efficiency stoves are responsible for increased production rates of POM-containing carcinogenic chemicals, it is clear that the potential exists for development of a significant population health hazard. Cooper[3] summarizes the urgency of the problem as follows, "emissions from RWC (residential wood combustion) sources must be considered a potential major threat to public health because of their highly respirable nature, the hazardous chemicals they contain, the available information relating these emissions, chemicals, etc. to health-related problems, the fact that they are emitted in residential areas, and that the emissions are increasing."

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INTERGRATED FARM ENERGY SYSTEMS: NEAR TERM

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The American agricultural system has made the maximum use of cheap energy and in so doing has made the productivity of the American farmer the highest known in recorded history. One American producer now feeds himself and more than fifty other Americans plus consumers throughout the world by providing for the enormous agricultural exports.

From the earliest time, agricultural productivity per worker increased very slowly as animal power, improved machinery, improved varieties and better management practices came into being. The most rapid change came at the close of World War II when mechanical power rapidly replaced human and animal power. Cheap energy in the form of petroleum allowed this to be a profitable and highly productive change.

As tractors replaced horses and mules, the potential production per worker increased greatly. As a consequence, not as many workers were required to produce food. The workers no longer required to produce food were thus able to produce other consumer goods, to spend time thinking and planning, and developing the many things which have produced the high standard of living to which we have become accustomed.

From a strategic and long range view, not all changes were for the best. The energy source for food production changed from the corn crib to the oil well. The high cost of farming equipment dictated long annual use and the land needed by the farmer was not always contiguous. This resulted in land being farmed several miles from the base of operation, and transportation of equipment became a factor.

Agricultural production is faced not only with rapidly rising prices for energy, but also with potential uncertainty as to supply. Thus, the modern farmer being dependent almost wholly on outside, even foreign, sources for energy is very interested in reducing his vulnerability for energy.

The energy for agricultural production today may be divided into six categories with about 30 percent of the energy used for field work, 25 percent for transportation,20 percent for irrigation, 12 percent in livestock production, 8 percent in crop drying and 5 percent in miscellaneous uses. The mobile operations--field work and transportation--will require liquid fuels whereas solid or gaseous fuels can probably be used for the remaining four categories. Thus, the requirements are fairly evenly divided between liquid fuels and other types.

The combinations of alternate energy systems which can be integrated into farm systems are almost as numerous as the number of farms which we have. The energy sources and methods of obtaining energy are, however, more restricted. With the exception of nuclear, geothermal, and tides, we must consider the sun as our energy source.

Solar energy and wind energy may be collected and used directly on the farm. Unfortunately these sources, while inexhaustible, are intermittent and have highly variable outputs. Because of these characteristics, some sort of storage must be provided or they must be backed up by some other source to insure a supply of energy when needed.

By the process of photosynthesis, growing plants store solar energy which can

be used at any time in the future if properly preserved. Normally we utilize only a portion of the plants which we produce, leaving the residue in the field to disintegrate. This material is not wasted, however. It provides ground cover to reduce erosion and as it disintegrate, provides nutrients and water holding capacity for the next crop. A significant portion of the residue can probably be removed and used for energy production without jeopardizing the production potential of the soil. Thus, in many situations it may be possible to produce food and energy at the same time. There may be situations when it will be desirable to use a portion of the farm to produce a specific energy crop to supply the fuel necessary to produce food on the remainder of the farm.

The nature of the alternate energy supplies is such that it is likely that there will be a mix of energy uses with the different forms being worked together to get a synergistic effect.

Operations which involve animals appear to have a great potential for developing integrated energy systems for supplying their energy needs.

Corn, which is the diet base for feeds, must be supplemented with protein and other addivities for most animals. When alcohol is produced from corn, the stillage contains a high percent of protein on a dry basis. Thus, both the protein supplement and fuel alcohol could be produced in connection with the operation. The manure could be collected and anaerobically digested to produce methane. The methane could be burned directly to produce heat for whatever process needed, or burned in an internal combustion engine to produce shaft horsepower for driving machines or electrical power generation. The waste heat from this operation would be used for many things, including the production of more alcohol and protein supplement.

In producing the methane, the manure will have lost mostly carbon and hydrogen. As a result, the percentage of nitrogen will be higher. The other important fertilizer elements will be essentially unchangead except for sulphur which will be lower.

Methane generation from crop residues also shows promise. These may be used in conjunction with animal manure, as the Chinese are doing. Another possiblity is the storing of these residues in underground pits and allowing them to decompose in a manner similar to sanitary land fills. The methane could be utilized as in the previous example. This type of generation would reach peak production a few months after filling and should be useful where large amounts of heat are needed in the winter. The residue from this generator would be used as fertilizer.

Another integrated system which would involve animals, is the production of liquid fuels from oilseed crops such as soybeans, suflower, or peanuts. The solids left after the oil is expressed would be used to provide the protein supplement and the oil collected to use as a diesel substitute. Some additives will probably be needed to reduce the viscosity and gumminess of the oil, but tests have shown that such oil may be able to replace the diesel oil. Again the manure from these animals can produce methane which can supply the energy for removing the oil, resulting in the maximum amount of liquid fuel production from the operation.

Several potential scenarios can be developed which would result in "closed cycle" operations with only the products of photosynthesis being used. One such operation would involve sweet sorghum. The leaves and tops would be stripped from the plant and left in the field. Thus most of the nitrogen would not be removed. The juice would then be expressed and fermented. The heat for distillation would be supplied by the bagasse through either direct combustion or gasification. The ashes which would contain minerals would then be mixed with the stillage and spread back on the field by the irrigation system. The alcohol would contain only the products of photosynthesis, and except for the inefficiences, all fertilizer removed by the plant would be returned to the soil for the next crop.

The use of crop residues, woody biomass or crops produced specifically for energy (from marginal food producing land) may be enhanced by the use of solar drying to increase the net energy output when used either as direct combustion or gasification. Gasification offers several advantages over direct combustion because of the versatility of the gas. With some cleaning, the gas can be used in internal combustion engines and the waste heat utilized as outlined earlier.

Wind energy may be used to provide mechanical energy, to separate hydrogen and oxygen from water or to provide thermal energy. Any of these forms of energy may be integrated with solar or biomass energy sources to provide the desired form of energy.

With expected development of photovoltaic cells and the integration of this energy with wind and non-food biomass, it should be possible to produce our food with renewable energy without sacrificing food.

THE USE OF BIOMASS FOR ELECTRICAL GENERATION AND COGENERATION: BONNEVILLE POWER ADMINISTRATION'S EXPERIENCE

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The Pacific Northwest is entering into a new stage in the planning and development of energy resources, with serious electric shortages in sight and with its hopes pinned largely on conservation and the rapid development of renewable resources during the 1980s. Until about 1970, the region was able to rely almost entirely on inexpensive electrical energy available from its extensive hydro resources. As the population and its energy needs increased, coal and nuclear powerplants were planned to meet the gap between supply and demand. Current forecasts indicate, however, that even with the thermal plants underway and scheduled, the region may be energy deficit each year during the 1980s. The completion dates of the coal and nuclear plants scheduled to come on line during the next decade continue to slip. Any additional delay in the construction of these large thermal plants will increase the projected energy deficits and make it even more imperative to develop other alternatives.

As one of the region's major power-planning agencies, Bonneville Power Administration (BPA) has been examining the alternatives through which the projected deficits could be met. The long lead times required for hydro, coal, and nuclear projects--the conventional means that have supplied the region heretofore--rule out the possibility that new projects of their kind, if started now, could be on line to help during this decade. Given the region's abundance of biomass, particularly wood, and the shorter lead times required to develop this renewable resource, the use of biomass for electrical generation and cogeneration is receiving much attention.

BPA is a partner in many studies with others. One is a joint BPA-U.S. Forest Service study of the feasibility of using forest residues from the Mt. Hood National Forest to fuel a generating plant. Preliminary calculations indicate that there could be enough residue within an average hauling distance of 45 miles to fuel a 25 MW plant. However, with the increasing demand for home firewood, it is likely that not all of the residue would be available for such a plant. A 25-MW plant would have a capital cost of about $1,900/kW, including interest during construction and escalation to 1985. If it were operated at a 75 percent capacity factor and publicly financed, the first year cost of energy in 1985 is estimated to be about 80 mills/kWh.

BPA has also been examining cogeneration. We contracted with Rocket Research to survey the region's potential for industrial cogeneration. We estimate that the region's total technical potential for cogeneration and condensing cycle generation is about 1400-MW capacity, excluding that which is already operating. If this capacity were developed, it could be operated with an average capacity factor of 65 percent. Over 80 percent of this potential is in the wood-processing industries. An economic analysis carried out as part of this work indicates an average cost of 40 mills/kWh (1983 dollars), based on typical public agency, tax-exempt revenue bond financing.

Although BPA does not build or operate generating plants under its current legislative mandate, our R&D spending authority has permitted us to provide partial funding for two feasibility studies of cogeneration projects. One project would be a 6- to 24-MW facility in Heppner, Oregon, using mill residue from Kinzua Corporation. The plant's capital cost escalated to an assumed operating date of 1983 would range from $2,388 to $1,637/kW. With a 75-percent capacity factor, the first year cost of energy would be 40 to 55 mills/kWh. The other project would be in eastern Lewis County, Washington, where eight lumber mills would supply fuel for a 25-MW plant and some industrial processes. The electricity could be generated at a cost of about 40 mills/kWh during the first year of operation in 1984, based on an escalated 1984 capital cost of over $48 million, public financing, and a capacity factor of 85 percent.

As a power marketing agency, BPA maintains an extensive high-voltage transmission system which is capable of carrying 80 percent of the electricity generated in the region. Because of this, we can provide services at the present time which are particularly valuable to cogenerators. Our contract with cogenerating Weyerhaeuser plants illustrates these services. Plants in Aberdeen, Longview, and Everett, Washington, produce an average of 54 MW of cogenerated electrical energy each week. The three local utilities transmit the energy to BPA, which in turn stores an equivalent amount of streamflow in the region's reservoirs. Nine industries which BPA serves directly have purchased Weyerhauser's cogeneration and we deliver that energy when the purchasers can use it. Subject to the hydro system's operational limits, we can also deliver the energy to the industries before Weyerhaeuser has delivered cogenerated power to us.

Several of the problems facing potential sponsors of biomass generating and cogenerating plants have been or are being resolved. Under the Public Utility Regulatory Policies Act, the Federal Energy Regulatory Commission has established rules to exempt many industrial generators and cogenerators from utility regulations and to require utilities to serve industries at reasonable rates and to buy power from industries at incremental rates. In the Northwest, our highly integrated transmission system and the hydro system's storage capacity greatly facilitate the marketing of industrially produced electricity. Together, these elements of the power system allow the conversion of intermittent sources of generation into a firm energy supply which can be more readily marketed and transmitted to virtually any purchaser in the region.

One issue remaining is the availability of fuel, despite the abundance of forest lands in the region. If an industry is to invest in a generating plant, it needs some assurance that adequate fuel will be available during the life of the plant. The use of more efficient harvesting and wood-processing technology is reducing the amount of residue produced per unit of timber processed. At the same time, the amount of residue available for use as a fuel is decreasing because the markets for home firewood, paper pulp, particle board, and other products are expanding.

One way to compensate for these developments may be to develop energy farms which could supplement the biomass fuels available from other sources. Under a U.S. Department of Energy grant, Seattle City Light began a 5-year study in 1978 to test the growth of two native species, red alder and black cottonwood, under intensive management on two 15-acre plots, one of which is on a BPA transmission right-of-way. Also deserving of in-depth examination is the use of less intensive management of species grown on other types of underutilized land or on commercial forestland during the period immediately following the harvest of the primary conifer crop. Energy farming could eliminate some uses of herbicides and, depending on the species chosen, reduce the need for fertilizing the reestablished forest crop.

BIOMASS USE FOR ISLAND UTILITIES

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Nowhere in the world has the effect of oil prices had a more pervasive and thoroughly detrimental effect on the economy than in Puerto Rico. An island of high population density, of no known fossil fuel resources, its whole planning for development was based on the utilization of the then cheap and plentiful Caribbean oil. The power utility is 99% dependent on oil and the large petrochemical industry is a major sector of the island manufacturing operations. Energy and thus industry have been priced out of world markets with a disastrous effect on the economy as a whole.

From 1940 to 1973 electric power demand grew at a yearly rate of 15%, requiring the doubling of generation facilities every five years. When the OPEC price increase was put into effect, load growth suddenly became negative and has stood at practically zero growth up to the present. The construction program which had been planned for such a fabulous growth had to be braked suddenly, including the cancellation of a 600 MW nuclear plant, which could not be justified at the present demand levels. However, a series of 300 MW coal-fired units are being planned for construction during the 80's.

Even though there is no indication that new generation could be justified by load growth tendencies during the present decade, the price of electricity has reached levels which disuade industrial promotion and affect hotel and restaurant services, thus affecting the tourist trade. Therefore, substitution for oil is of prime importance, and the quest for fuel alternatives has been a continuing process.

Biomass appears to be the best alternative, with the capability to replace not less than 35% of the oil used for power production. The presently considered uses of biomass are the following:

a) Garbage and refuse incineration for the production of electricity. A 20,000 KW plant will be built by the Waste Refuse Authority. The total potential of this source is around 60,000 KW with a total saving of 600,000 barrels of oil per year.

b) Partial conversion of the sugar industry into energy production. This project contemplates the use of at least 50,000 acres out of the 100,000 acres now devoted to sugar production. The objective is the production of high-fiber residues and bagasse for direct burning and molasses for the production of ethanol. Present tests being made at the Experimental Station of the University of Puerto Rico by Dr. Alexander and others have produced species with fiber yields approximately four times those obtained at present. The utilization

of these species and new agronomical methodology results in yields of approximately 40 tons of dry fiber per acre with economies of up to 100 barrels of oil per acre.

The CEER - U.P.R. (Center for Energy and Environmental Research - University of Puerto Rico) has made arrangements with the Commonwealth Government to try out in a sugar mill all of the new technologies and also new methods for fiber and bagasse drying by the utilization of solar heaters and hot boiler flue gases.

This project has faced some opposition from circles within the P.R. Department of Agriculture. It has been thought that this acreage should better be dedicated to rice and other crops as part of the efforts to reduce food importations. However, at present both viewpoints are being harmonized and a cane based energy program should be started very soon.

c) Two aquatic plant growths which have been a nuisance in the past are at present under study for their potential energy yields. One is the production of seaweeds which grow in enormous quantities especially near the effluvia of rum distilleries. Seaweed has been a very serious nuisance at the Palo Seco Steam Plant.

Another biomass product of great interest is the utilization of water hyacinths which grow in profusion in some of our water and hydro-power reservoirs. Although no definite economic evaluation of the energy yields of these resources is available, these water plants will be closely studied in the future as sources of energy.

d) Manure, sewerage and crop residues of small farms will be processed in anaerobic digestors for the production of methane. A pilot plant under the auspices of CEER is now in operation in the south coast of Puerto Rico.

Conclusions - Biomass appears to be a viable source of energy with the potential to reduce considerably oil imports in Puerto Rico. The most promising source of biomass appears to be the partial conversion of the sugar industry to energy production. However, garbage and refuse incineration and methane production from seaweed, water hyacinths, waste, sewage and refuse will also contribute to reduce the island's dependence on imported oil.

PROMOTING BIOMASS CONVERSION TO ENERGY IN CALIFORNIA

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In 1979, the legislature of the State of California determined that a considerable quantity of energy could be made available to certain sectors of the state through the use of agricultural and forestry wastes. To foster such energy development, the legislature enacted the State Agricultural and Forestry Residue Utilization Act (SAFRUA) and mandated that the California Energy Commission undertake a biomass energy promotional program, the Biomass Conversion Demonstration Program, in accordance with an established schedule.

The SAFRUA related work activities undertaken by the CEC with the technical assistance of Envirosphere Company, its contractor, have included:

a. The completion of environmental studies for the Biomass Program itself and individual projects, when required.

b. Solicitation for and review of proposed biomass energy projects seeking funding support under SAFRUA.

c. Selection of projects for funding support which consists of no interest loans covering the costs of equipment procurement or project construction with repayment required as soon as identified project performance criteria are achieved.

d. Technical assistance (engineering, economic, environmental) to projects receiving funding.

e. Ongoing reviews and evaluations of funded projects.

As indicated earlier, the Biomass Program being conducted by the CEC is intended to promote the use of agricultural and forestry wastes as an energy resource. The energy conversion processes covered under the Program include direct combustion, gasification and methane fermentation. In the five year life of the Program, a minimum of twenty projects are to be funded and based upon the results of the first year, considerably more than twenty will be funded before the Program ends.

Although the Biomass Program is not yet a year old, enough work has already been undertaken to illustrate the types of problems that can occur. These include the following:

a. Although biomass projects generally have few environmental impacts, certain large projects, especially of the direct combustion type, can have potentially significant environmental impacts (especially with respect to impacts on air quality).

b. The gasification technology remains somewhat unproven and has yet to receive significant acceptance from the agricultural and forestry communities.

c. Many biomass project proponents lack the expertise to undertake even a small project without sufficient technical support.

In spite of the difficulties enumerated above, the California experience with the Biomass Program has thus far been a successful one. Ten projects are now either under funding or will shortly receive funding support; generic environmental documents have been generated to satisfy the requirements of the California Environmental Quality Act and to avoid the need for project specific environmental for a large number of projects; and specific guidance is being provided to prospective proponents of biomass projects. Most importantly, the way has been opened for the State of California to use a portion of its biomass residues as a substitute for conventional sources of energy.

INTEGRATED ENERGY SYSTEMS FOR THE SUGAR INDUSTRY

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The Hawaiian sugar industry has advanced significantly towards its goal of energy self-sufficiency and may, in the near future, be a net exporter of energy.

The industry produces roughly one-tenth of the electric power generated in the state via combustion of bagasse, the residual fiber in sugarcane. In the past, little effort was made to improve boiler efficiencies since bagasse, regarded as much a waste product as a vital source of fuel, was burned largely as a convenient means of disposal. Recently however, escalating oil prices have encouraged the development of more efficient furnaces and boiler operations. At present, 2.7 million tons of bagasse (equivalent to 2.6 million barrels of oil) is burned as fuel annually. Superheated steam from the boiler is expanded through turbine-generators to produce electricity for use in the factory, with excess sold to utilities. Steam from the turbines is then extracted at medium and low pressures for use in sugar processing. The efficient, simultaneous production of process steam and electricity, "co-generation," has enabled the processing phase of the industry to be completely energy self-sufficient and has contributed significantly to the statewide power generating capability.

Three hundred and fifty thousand tons of trash (dry-basis), the leafy portion of sugarcane, is produced industrywide (equivalent to 630,000 barrels of oil); however, only one-fifth of the trash produced is currently used as boiler feed while the rest is discarded. Clearly, as oil prices increase, combustion of trash will be more commonly practiced throughout the industry.

The major obstacle to efficient combustion of bagasse and trash is their high moisture content, since combustibility deteriorates as moisture increases and a substantial portion of the energy of combustion is wasted in heating the excess moisture discharged with the flue gas. Several methods of removing moisture from these fuels to minimize the unrecoverable energy are currently being examined, viz., mechanical dewatering of cane trash, solar and forced-convective drying of bagasse, and compressing bagasse into dry, easily stored pellets. To ensure that each alternative yields a net energy gain, an energy audit is conducted, whereby the energy input, e.g., fuel, electricity, and steam, is deducted from the energy output to determine the real energy profit of each alternative. Naturally, every effort is made to recover waste heat through the use of recuperative devices such as air and feed water heaters, while boiler design and control improvements are constantly being implemented.

For the immediate future, improved bagasse and trash power generation appears to be the most expedient means of reducing the state's dependence on foreign oil. Unfortunately, this type of energy cannot be exported from the

state. However, a joint study conducted by the Hawaii Natural Energy Institute and the Hawaiian Sugar Planters' Association is currently underway to determine the best process for manufacturing an exportable fuel, ethanol, from molasses. The Hawaiian sugar industry produces approximately 320,000 tons of molasses annually, which is capable of yielding 22.8 million gallons of ethanol. To improve the economics of ethanol production, several environmentally acceptable alternatives of handling the stillage generated during distillation have been examined, with production of an animal feed combined with potassium recovery appearing to be the most favorable alternative. Vehicle performance tests using gasoline-ethanol and diesel-ethanol blends with both anhydrous (99.6%) and industrial (96%) alcohol have been conducted with encouraging results. Pilot plant production of animal feed from stillage and feeding trials are scheduled.

While unprecedented effort is being made to increase energy production, energy conservation is also emphasized. Energy-efficient manufacturing equipment such as multiple-effect evaporators have substantially decreased steam consumption in the factory, while improved field equipment and practices have resulted in more efficient fuel use.

In addition to the aforementioned sugarcane derivative, other renewable sources of energy are being used or are being examined for possible use in the industry. They include hydropower, which accounts for roughly 10% of the electricity generated by the industry, solar energy for sugarcane seed treatment, combustion of wood chips in bagasse furnaces, and geothermal energy to supplement bagasse-generated steam.

Ethanol from molasses, combined with improved recovery of steam and electricity from existing and new sources of fiber, may soon allow sugar plantations to become energy plantations as well. Through this integrated approach of fuel preparation, co-generation, efficient use of steam and electricity in processing, production of an exportable fuel, and conservation, the Hawaiian sugar industry may soon achieve its goal of complete energy self-sufficiency.

COMBUSTION TECHNOLOGY FOR INDUSTRY AND AGRA-BUSINESS

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Bio-mass burners for on-farm and industrial uses are literally "busting out" all over. Many firms are already on the market with commercially-available burners designed to turn straw, hay, weeds, shelled corn and other bio-mass materials into heat energy for drying crops, distilling alcohol for fuel, and for heating homes, livestock confinement buildings, manufacturing plants and office buildings. This report, accompanied by slides, focuses on latest new developments which have been featured in recent issues of FARM SHOW magazine, published by the author at Lakeville, Minn. U.S.A.

Tractor Generates Its Own Fuel "On The Go" -- "You can't believe the simplicity of the wood-gas system. It's wondrous to behold," reports James Bohlen, director, Greenpeace Experimental Farm, Rt. 1, Denman, British Columbia, who equipped a 1947 Ford Ferguson tractor to generate its own fuel "on the go". Bohlen believes wood-gas generators, which were popular in Europe during World War 11, can be updated and refined to play a key role in beating the high cost of fuel for farm tractors, trucks and cars.

Look What He's Doing With Smolder Energy -- Innovative Ohio farmer-manufacturer George Woods, of Prospect, has devised an underground "furnace" (a 15 ft. deep smoldering pit) to heat his home and barn. He fills the pit with alternating layers of coal dust, cinders and other combustibles. Vent pipes carry oxygen into the pit. Across the top, Woods heaps up a mound of wood chips, straw, grass, manure and other items that will compost rapidly from the heat of the pit. The pit itself is laced with old steam radiators connected with 1 in. diameter pipe. The pipe runs underground to the house, carrying water which has picked up heat in the smoldering pit furnace.

New "Burn Anything" Residue Burners -- Latest new developments include the Crop Residue Burner, introduced by Middle States Manufacturing Co., Box 788, Columbus, Neb. For crop drying, it injects the products of combustion directly into the air stream, the same as a gas or propane fired crop dryer -- without any odor or smoke contamination of the grain being dried. Handles 1,500 lb. bales of straw, cornstalks and other bio-mass materials. Bales are hoisted into the burner with a tractor loader and are fed automatically into the burning chamber.

Heat Your Home With Shelled Corn? -- "You'll get more from your corn or other grain crops if you burn them for fuel," says John Finnegan, co-inventor of this first of its kind self-stoking, completely automatic furnace designed to burn shelled corn or other grains. Finnegan and partners Dennis Dammann and Dale Flickinger formed a new company called Solid Fuel Systems, headquartered at Paynesville, Minn., to produce production models ranging up to 1,000,000 btu's. The portable furnace can be used as a crop dryer in the fall, then moved in winter to heat your home, workshop or livestock buildings, or manufacturing or office buildings. Inventors note that, with fuel prices approaching $2 a gal., corn will have to reach $7.25 per bushel to out-price shelled or ear corn in this new-style bio-mass burner.

"Cowpower" Energy System -- Just 15 cows provide enough btu's to heat a 2,000 sq. ft. home, says Brian Ramlow, of Atmospheric Energy Systems, Madison, Wis., manufacturer of this new "wrinkle" in combustion technology that captures cows' body heat. "Cowpower" can be used to heat your home, livestock barn, office or manufacturing building, or even as a heat source for an on-farm still, reports Ramlow.

"Breakthrough" Furnace Burns Anything -- You've never seen anything quite like this latest new chapter in combustion technology for industry and Agra-Business. Introduced by Dunn Energy Systems, c/o Miller-Meester Advertising, Minneapolis, Minn., it's completely self-contained and goes outside the home or other building, making it easily adaptable to new or existing homes or buildings. The new "burn anything" furnace burns with the complete efficiency of an incinerator and only has to be fired once every three or four days. Heat is stored in a solid bank of gravel measuring about 5 ft. square and 12 ft. high. Turns old tires, cobs, corn stalks, wood, paper, waste crankcase oil -- virtually anything that will burn -- into "free" heat for heating homes, barns, and manufacturing plants or office buildings.

A DEVELOPING HAWAIIAN ENERGY PLANTATION

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Background

As recently as 1972, four Hawaii sugar plantations north of Hilo on the Big Island of Hawaii, each with its own mill, were producing 120,000 tons of raw sugar and 30,000 tons of molasses, a principal by-product. State-of-the-art technology employing bagasse (the residual of cane fiber after removal of sugar juices) as the principal fuel allowed the mills to co-generate enough electrical power to supply their own needs, supplemented in some instances by small hydroelectric generators.

Today these four sugar mills have been replaced by a single mill owned by an agricultural processing cooperative, Hilo Coast Processing Company (HCPC). Farming of 26,000 acres is a separate operation, with Mauna Kea Sugar Company growing 80% of the sugarcane and over 250 independent growers producing the remaining 20%. Historically, the thermal efficiencies of Hawaiian sugar mills have been poor because the supply of bagasse fiber, especially at larger mills, substantially exceeded the amount required for fuel to power mill operations. However, EPA and State regulations prohibiting dumping of excess cane trash and bagasse in the ocean have made biomass incineration the only practical economic alternative.

Current

These conditions resulted in the natural evolution of a mill designed to fully utilize bagasse supplies. The HCPC mill has a high pressure boiler (1,250 psi) generating about 385,000 pounds of steam per hour. Electrical power is generated by a steam turbine-generator set to reduce the steam pressure for sugar processing to 160 psi operating pressure. A 23-megawatt (mw) generator provides 4 mw for internal use and exports up to 17 mw to the Big Island public utility. In 1979, the delivery to the utility exceeded 100,000,000 kwh, meeting more than 20% of the total Big Island requirements. At this time, the combined HCPC milling power production operation requires about 50,000 barrels of supplemental fuel oil per year. Revenues derived from the sale of power have assumed an important position in an industry that has generally been recognized as marginal.

Near Future

Two projects are being implemented that will advance the "energy plantation" concept at HCPC in the next year. First, a major improvement in thermal efficiency will be gained by taking advantage of the 450°F stack gas now being exhausted to the atmosphere. A $1,200,000 bagasse dryer will be installed adjacent to the HCPC mill. Bagasse with moisture content (mc) of 50% now being fed into the boiler, will be dried to 35% mc, increasing the BTU's available to produce steam. HCPC's goal is to substantially reduce the 50,000 barrels of oil still being burned annually.

As a secondary benefit, it may be possible to increase amounts of electrical power available for export. If only 25,000 barrels of oil are saved each year, the project should have a two-year payback.

Near Future - continued

Secondly, with the assistance of a $900,000 U.S. Department of Energy (DOE) grant, HCPC is conducting a feasibility study into the use of molasses as feedstock and excess process steam to produce about 20,000,000 gallons of ethanol annually for blending with gasoline and sold into the emerging Hawaiian gasohol market. Co-generated electrical power would be available for internal electrical needs and, subject to study findings, bagasse from the dryer could be channeled into a smaller secondary biomass boiler as required. The DOE study is intended to identify process design and to provide definitive engineering with the objective of placing an ethanol plant in operation by mid-1983.

Mid-Term Opportunities

Sugar on the Hilo Coast normally is grown up to elevations of about 2,000 feet. Above this elevation are thousands of acres of forest land capable of being developed into tree farms. Another DOE-supported study there is investigating and demonstrating optimum production techniques for growing and harvesting eucalyptus trees. Varietal testing; fertilization, herbicide and pesticide practices; spacing studies; harvest and hauling techniques; and boiler firing practices are being investigated with the goal of producing high value biomass "energy chips" for multiple uses.

Also, the Hawaiian sugar industry may develop a higher value use for its bagasse other than as fuel. When treated with a process recently developed by C. Brewer and Company, Limited, bagasse becomes a "high fiber" animal feed similar to alfalfa. As eucalyptus "energy chips" become available at competitive prices, they may be substituted for bagasse, releasing it for processing into the cattle feed. This use has the potential to develop into a $100,000,000 per year industry for Hawaii.

Longer Term Opportunities

Ethanol can be developed from cellulosic feedstocks as well as directly from sugarcane juices. Consequently, development of geothermal energy in Hawaii may result in a lower cost energy source that could divert bagasse and wood chips from fuel needs to cellulose-based ethanol production. If fuel prices continue to outpace inflation in the general economy, now unrealistic economics also may reverse and provide "energy products" from sugarcane more valuable than sugar. As petroleum-based feedstock becomes less price attractive and ethanol production costs are driven down by increasing volume and improved technology, an entire line of sucro-chemical products may become economically feasible, including a multitude of chemical products derived from ethanol.

Conclusion

As the need for renewable energy resources intensifies, a revolution in the sugar industry may be in the offing. Although the future is still not clear, co-generated electric power and power ethanol production already have evolved as viable new energy products of a sugar processing enterprise.

LATEX-PRODUCING PLANTS AS A SOURCE OF HIGH ENERGY LIQUID FUELS

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The use of biomass as a renewable resource for the production of fuel or chemical feedstocks is receiving increasing attention. Two distinct approaches are possible for energy farms. Either whole plants can be harvested as in a biomass plantation, or plants capable of producing reduced photosynthetic materials can be cultivated. In the latter case, the net product is a derivative of the total biomass, and the process would be unlike many other biomass systems where the whole plant is burned for its heat value. Conversion processes for hydrocarbon-like extracts are expected to be more efficient and less energy demanding, since the material is already in a reduced state. Suggestions that certain plant species might serve as alternate sources of liquid hydrocarbons (1) have led to several investigations, in particular involving Euphorbia lathyris. Buchanan and coworkers evaluated several hundred plant species as "energy farm" candidates and identified Euphorbia lathyris as one of the few potential hydrocarbon producing crops. (2) More recently Hinman and coworkers (3) have studied the cultivation and agronomic practicality of this crop, among others, in field plots in California and Southwestern U.S. Results of these tests should give us much information on the practical availability of the resource in different climatic areas.

Our own research since early 1977 has touched on all three necessary steps in the development of an alternate fuel from biomass:

a) Agronomy and cultivation procedures;
b) Harvesting and treatment of biomass to produce the desired extract;
c) Processing the extract for conversion to conventional hydrocarbon fuels.

The first field trials were carried out in Southern California in 1977 and 1978 (4). From results on small plots in which E. lathyris was planted on 1-foot centers we estimated a biomass yield of 11 dry tons per acre. The yield experiments are being repeated this year in San Jose at the Deciduous Fruit Field Station, starting with both seeds and seedlings.

Reduced photosynthetic material can be obtained from the dried plant material by hot solvent extraction. Various solvents can be used for the isolation of different plant constituents. In one such extraction scheme acetone is used, and about 8.5%w extract can be produced having a heat of combustion of 16,000 BTU per pound. It is a complex mixture, mainly triterpenoids, averaging between 400 and 500 in molecular weight. At the yields so far obtained, this product would amount to about 6 barrels per acre. A substantial amount of a more polar fraction can be obtained from the residue by further extraction with methanol. This second fraction isabout 30%w of the dried plant and consists mostly of fermentable sugars. (5) The yield of fermentation alcohol from this extract would amount to another 6 barrels per acre.

The conversion of the acetone extract of E. lathyris into hydrocarbon fuel has been tried with some success (6) by Weisz and coworkers at Mobil Research and Development. Using a shape-selective zeolite catalyst they have obtained an

80-85% yield of a mixture that closely resembles high octane gasoline.

Thus, all the steps from agriculture to fuel production are being investigated but the results are still quite preliminary. Since Euphorbia lathyris and other hydrocarbon producing crops are new species from the point of view of cultivation, their agronomic characteristics, requirements, and yield potentials are not yet well known. A recent study by SRI International on the feasibility of growing Euphorbia lathyris for energy usage identified as major uncertainties the feedstock cost and supply. (7) This conceptual process study is based on solvent extraction of field dried plants at 1000 tons per day, and recovery of the sugars by water extraction. Credit is given for the sugars at 4¢ per lb. (base case) or 6¢ per lb. (optimistic case). The overall process uses the cellulose (bagasse) of the plant to generate the energy required for solvent extraction and recovery. According to this model, after recovery of the useful products, a considerable quantity of bagasse is left over. If one includes in this model an estimate of the required energy input for cultivation, the entire process still remains energy positive. (8)

Based on this study, the estimated product costs are greatly dependent on the method of cultivation. In areas such as California where irrigation is required, one barrel of "oil" from Euphorbia lathyris may be produced for $100 (optimistic case). In a geographic region where irrigation requirements are minimal, the feedstock costs would be significantly lower. Consequently, one barrel of "oil" from Euphorbia lathyris grown in the Midwest is estimated to cost $43.

Comparison of a new crop such as Euphorbia with an established one like sugar cane, which yields ethanol, indicates that in terms of energy yield of liquid fuel per acre/yr., Euphorbia lathyris is comparable. The liquid fuel yield from sugar cane is 45 million BTU/acre/yr. in the form of ethanol. (9) The Euphorbia lathyris yield is 25 million in the form of hydrocarbons and 20 million in the form of alcohol for a total yield of 45 million BTU/acre/yr.

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TERRESTRIAL ENERGY FARMS

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Energy farming is considered as a major prospect for supplying energy feedstocks in the future. This consideration anticipates a continually increasing economic need for biomass energy due to increasing prices for fossil fuels through the foreseeable future. This paper provides an overview of the concept of terrestrial energy farming. Aquatic energy farming concepts are to be covered in a subsequent paper in this session.

Energy farming may be defined as the cultivation of a crop for use as an energy feedstock. Two prime criteria are evident in this definition: (1) the intent to use the commodity for conversion to energy end-product, and (2) the use of agricultural crop management techniques to accomplish that purpose. The first criterion distinguishes energy farming from food and fiber farming, and the second distinguishes energy farming from other biomass feedstock collection systems. This definition thus excludes the collection of crop residues and logging residues for energy conversion, since these feedstocks are by-products from farming systems designed to produce food and fiber. Also excluded is the harvest of natural vegetation for energy conversion, since crop management practices are not used. The definition does not specify, however, the level of crop management to be practiced. Hence, either intensive or minimal management practices could satisfy the criterion.

Energy farming can be divided into two categories, depending upon the nature of the feedstock produced. If the purpose is to produce raw biomass as a multipurpose feedstock, the total above ground portion of the crop is the item of interest. On the other hand, a specific component of the crop such as sugar, starch or oil that can be converted to a specific energy product may be the item of interest, with the raw biomass residue considered as a secondary feedstock. The reason for distinguishing between these two categories is the different crop development approaches and crop management practices that are required.

Initial attention in R&D programs has focused upon developing tree species as energy crops, largely for traditional reasons. Wood and bark collectively provides a more dense feedstock than other forms of biomass, and due to its high lignin and resin content also has a higher heating value than other forms. It is believed that yields of 10-20 dry tons per acre-year can be achieved in the future from intensively managed short rotation systems developed for temperate species. Yields of this magnitude appear possible with current technology in the tropics. A large number of species offer promise as silvicultural energy crops. Analysis of silvicultural systems project that feedstock could be produced at a cost of $1.00 to $2.00/$10^6$ Btu. Herbaceous biomass species have received less attention than woody species to date, but merit a concerted R&D effort. It is anticipated that herbaceous biomass yields and costs could parallel those of woody species.

Cultivation of sugar and starch crops for ethanol production is already practiced, and can be expected to increase dramatically in the near-term. As the demand for alcohol fuels increases and newer conversion technologies are developed, however, lignocellulosic crops may largely replace sugar and starch crops as a feedstock for ethanol production.

Prospects for the farming of new crops to produce natural hydrocarbons such as oils, resins, waxes, etc., also offers potential. Vegetable oils such as soy oil and sunflower oil have been demonstrated as suitable extenders for diesel fuel. A variety of petrochemical substitutes could be extracted or refined from the contents of plants as Euphorbia spp., jojoba, and guayule. A very large number of such "hydrocarbon species" exists which merit research attention.

Other forms of energy farming that deserve examination include the minimal management of natural stands of woody or herbaceous species utilizing marginal croplands for energy farming, developing arid land species and crop management practices for arid land species, and agroforestry.

The outstanding problem confronting energy farming is unfavorable economics. The cost of biomass feedstocks must not only compete favorably with those of conventional energy feedstocks, including coal, but biomass crops must also compete favorably as cash crops with conventional food and fiber crops that could be produced on the same land. Ongoing R&D programs coupled with continually escalating energy product costs should result in increasingly favorable economics for energy farming as time goes by. R&D should be focused on species selection and improvement, developing cost and yield-effective crop management practices, and scale/applications analyses.

The primary issue confounding the concept of energy farming is land availability, or more precisely, competition with conventional farming and forestry for land use. Because of this issue, and expectations that food and fiber production will continue to predominate in the use of prime agricultural land, efforts must be increased to develop suitable methods of using marginal and arid lands for selected energy farming systems.

GENETIC ENGINEERING FOR GREATER ENERGY EFFICIENCY IN SUGARCANE

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Sugarcane (Saccharum spp. hybrid) is Hawaii's most important agricultural crop. Sugarcane, sorghum, and corn are distantly related crop species considered to be among the most efficient in converting solar energy into renewable biomass energy through the process of photosynthesis. Because of favorable winter temperatures, sugarcane in Hawaii has the advantage of continued, year-round growth; harvesting, and hence interruption of growth occurs on the average only once every two years. These factors make sugarcane as grown in Hawaii one of the world's most energy-efficient crops, whether measured in terms of an energy input/output ratio or in terms of net energy output per hectare per year.

Production and energy balance data for Hawaii's 1978 sugarcane crop are shown in Table 1. During 1978, Hawaii's sugar industry processed 8,108,400 net metric tons cane (fresh wt) from 40,235 hectares. From 2.6 million tonnes bagasse and leafy trash (1.3m dry wt) burned in boilers, 3.69×10^{15} cal. of heat (91.7 Gcal/ha ≃ 60% efficiency) was produced. This energy, along with 0.78×10^{15} cal. of heat produced from other sources, largely oil, supplied factory processing needs and was used to generate 598×10^{6} kwh electricity for plantation use and sale of excess electricity to local utilities. Plantations account for 42%, 38%, 23%, and 2% of the total electricity generated on Hawaii's four Sugar Islands of Hawaii, Kauai, Maui, and Oahu--almost 10% of the total generated in the State.

TABLE 1. Hawaiian sugarcane energy balance-1978 (estimated)

Component	Metric tons (Dry wt)	Tonnes/ha (Dry wt)		Gcal/ha (Energy)
OUTPUT				
Sugar (96DA)	933,400	23.2		91.6
Molasses	230,100	5.7		21.7
Bagasse	1,311,700	32.6		150.0
Leafy trash	315,800	7.8		35.9
Total output	2,791,000	69.3		299.2
INPUT				
Cultural				16.0
Gasoline			*1.6*	
Diesel			*5.2*	
Electricity (primarily irrig.)			*5.9*	
Invested (fert., pest., ripen.)			*3.3*	
Factory processing				74.5
Total input				90.5

A significant contribution toward Hawaii's goal of energy self-sufficiency will come through increased sugarcane biomass production. The research expended to genetically improve sugarcane--development of cultivars higher in dry matter per hectare than current commercial varieties--represents a sound investment. Sugarcane yields realized during the past decade have been about double the yields of the early 1920's which was just prior to the Industry's conversion to Hawaiian-bred cultivars. At least 50% of the increase in yields since the early 1920's is estimated to be genetically based.

At HSPA, sugarcane breeders intend to make substantial genetic improvements in the future by (1) reevaluating and, to some extent, altering selection criteria as

part of the on-going Breeding and Selection Program, (2) utilizing all available germplasm to a greater extent, and (3) exploring the broadening array of non-conventional genetic engineering tools that are becoming available to the breeder.

Selection Criteria. In order to increase energy efficiency in future cultivars, those traits which maximize energy output and minimize input will have to be emphasized. Data show that, by removing the selection pressure for sugar per tonne of cane, it is possible to select many cultivars that yield much more dry matter than cultivars grown commercially for sugar production. During the past 3 years, HSPA breeders have intercrossed cultivars high in total cane tonnage (with the stipulation that tons sugar/ha be at least equivalent to standard commercial cultivars) as part of their breeding program. Canes that establish early and grow rapidly, with heavy tillering and good ratooning (regrowth after harvest) habits minimize energy needs for culture.

Changes in cultural practices may make possible a more direct selection for biomass production. For example, the use of potent chemical ripeners may permit many otherwise unacceptable cultivars high in biomass to achieve Industry standards set for sugar production. One may also speculate that if it became economically attractive to convert sugars or cellulose in sugarcane to other chemicals (such as the production of ethanol from molasses), selection strategies could be changed to emphasize total sugars either directly or through cellulose conversion.

Exotic germplasm. Utilization of new germplasm sources increases genetic variation for yield related traits and resistance to diseases and insect pests--variation that may be particularly valuable as selection criteria are altered. For example, wild Saccharum spontaneum and S. robustum clones hybridized with commercial cultivars, both in Hawaii and Louisiana, have resulted in progeny high in dry matter production. In Hawaii, derivatives of certain S. spontaneum x commerical crosses have performed exceptionally well in upper elevations where cool temperatures prevail and long-age cropping is practiced. These same derivatives also exhibit rapid early growth, heavy tillering, and strong ratooning habits. The most valuable source of S. spontaneum germplasm for Hawaii was from seed collected in the upland areas of Thailand in December 1955. The need for collection of germplasm in areas with conditions similar to ours is urgent and represents one means of achieving future breakthroughs in biomass production.

Non-conventional genetic engineering methods. One means of genetically altering commercial-type clones (2n=100-130) is to induce genetic change via tissue culture/cell suspension techniques. Sugarcane sub-clones derived through tissue culture frequently vary from the original clones. Colchicine, a chemical that inhibits cell division without inhibiting chromosome duplication, has made possible the doubling of chromosomes in several cultivars at HSPA. One of these cultivars was successfully crossed with several Hawaiian cultivars. Progeny of these crosses and subsequent progeny through further backcrossing have a range of chromosome numbers from 100 through 240. We are currently investigating the possibility that a higher optimum chromosome number exists at which sugarcane cultivars will exhibit a higher sugar, molasses, and/or fiber yield potential.

We are optimistic that, with the genetic tools currently available, and with the adoption of cultural practices that maximize biomass production, sugarcane biomass production could be substantially increased during the next 20 years.

MARINE BIOMASS ENERGY SYSTEMS FOR THE PRODUCTION OF METHANE

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Gas Research Institute
Chicago, Illinois

The Gas Research Institute has made a strong commitment to developing marine biomass as an energy source since biomass grown in the open ocean could be used to provide almost unlimited quantities of methane. This resource is very promising because area, nutrient, and water availability are not limiting as they are on land. For these reasons, GRI has been conducting a unique, integrated program to develop open ocean farm systems for the production of methane.

This program was started by the gas industry in 1974 in recognition that a renewable source of methane was essential to the long-range future of adequate gas supplied from domestic resources. The Marine Biomass Program has the overall objective of developing a system for the production of methane gas on a commercial scale that will provide a major contribution to the nation's gas supply. The approach utilizes the concept of providing a renewable resource, macroalgae grown on an open ocean farm, in order to capture and store solar energy through the natural process of photosynthesis. The macroalgae is then converted to methane which is used to supplement the national natural gas requirement.

The macroalgae will be grown and cultivated in the ocean on an artificial structure with fertilizer being supplied by nutrient-rich deep ocean water. The marine farm concept has the major advantages of: making use of the ocean to provide cultivation area, thereby avoiding competition with land-based food, feed, and fiber crops; utilizing the vast reservoir of nutrients that are found in the deep ocean waters rather than the energy consuming forms of commercial fertilizer; and, requiring no fresh water which is becoming increasingly limited and more expensive for land agriculture. An additional potential benefit of the marine biomass concept is found in the production of energy saving by-products such as animal feed supplements and fertilizer.

Past and present work on this program has had the primary objective of determining the technical and economic feasibility of a system for the production of methane (or substitute natural gas) from giant California kelp, (Macrocystis pyrifera), grown on man-made structures in the ocean. Giant California kelp was selected as the marine biomass to be used as the result of a study conducted by the California Institute of Technology in 1974. The characteristics which led to its selection were: its high growth rate, its size, structure, and growth patterns which allow it to be mechanically harvested, its long life and continuous or year-round growth cycle.

Studies and economic analyses of potential commercial systems have shown that kelp yield per acre of ocean farm, using deep ocean water as the source of fertilizer, is one of the key parameters affecting both initial capital requirements and unit gas costs. In order to provide a data base on kelp yield, we have, in cooperation with the Department of Energy, designed, constructed, and installed a biological test farm in the open ocean approximately five miles off the coast of Southern California. This experimental test facility is to be used as an open-ocean laboratory to conduct kelp yield experiments on adult kelp plants in a controlled fertilization environment.

During December of 1978, the California Institute of Technology selected more than 100 adult California kelp plants 40-70 feet long from natural beds and attached these plants to the offshore test structure. A task was then initiated to monitor the plants as well as the ocean environment in the area of the test facility. Due to several storms, which occurred in rapid succession and the subsequent destruction of the current retardant curtain, the kelp plant population on the test structure was reduced. Storm induced currents and waves as well as resulting motions of the farm caused abrasion of the plants against the test farm structure. Measurements made during the period when the kelp plants were intact showed that the kelp absorbed nutrients from the water upwelled by the test facility and initiated new growth at the bases of the plants.

After this experimental period, it was observed that juvenile kelp plants had attached to the test structure. These juvenile plants developed from spores that had been released by the adult plants. Juvenile plants that were fertilized with upwelled water showed average lengths that were about four times greater than those observed in similar plants in natural beds. These observations are considered extremely significant since it was proven that kelp can grow and reproduce itself in the open ocean when fertilized by upwelled water. The ability of kelp to reproduce also suggests that planting ocean farms will be feasible with relatively little cost.

During 1980, the current and wave-induced stresses on adult plants have been studied in order to reduce damage caused by these forces. The use of elastic lines and damping plates has been shown to greatly minimize the motions of the plants. Analyses of these experiments have provided information which will be used to design farm modifications which will prevent damage to the plants and allow kelp yields to be determined in the open ocean.

In addition to the biomass yield studies, work on the conversion of kelp to methane has resulted in the highest sustained methane yields reported in the literature for biomass (e.g. 4.9 SCF/lb VS). Work in the conversion area is currently concentrated on the development of optimized inocula and the development of unconventional digester processes (e.g. multiple phase, attached film, plug flow, etc.). Other areas of research include alternate site experiments, the development of various genetic strains of Macrocystis pyrifera to maximize biomass and methane yields, the investigation of other macroalgal species, and the study of by-product recovery. The results of these diverse studies are continuously being incorporated into ongoing systems and economic analyses.

GRI's progress has been encouraging. A major milestone has been attained by proving that kelp can reproduce itself and grow in the open ocean when fertilized with upwelled water. Within the next three years, it is expected that the feasibility of the marine farm concept can be determined. Emphasis on the program is currently being placed on modifications to the open-ocean test farm which will allow sustained kelp yield data to be collected. In the gas conversion area, emphasis is being placed on the development of new, more efficient digestion processes. Though many problems remain before ocean farming becomes a reality, the vast potential of marine biomass as a plentiful, renewable energy resource makes the continued investigation into the feasibility of the ocean farm concept essential.

TROPICAL GRASSES

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Río Piedras, Puerto Rico

Tropical grasses from Saccharum and allied genera are being studied in Puerto Rico as intensively-produced sources of boiler fuel and molasses. Emphasis is directed toward: (a) Maximization of sugarcane's total biomass rather than sucrose; (b) year-round fuels production through the utilization of alternative tropical grasses during sugarcane's off season; and (c), mechanized production technologies for fibrous, thin-stemmed tropical grasses to be managed as solar-dried fuels and feedstocks.

TABLE 1. Optimal Yield for three Categories of Tropical Grasses

Grass and Category	OD Tons/ Acre/Year
Sordan 70A (Short Rotation)	21.2
Napier Grass (Intermediate)	33.0
Sugarcane (Long Rotation)	33.6

Tropical grasses are conveniently grouped into three management categories based on the time required to maximize dry matter yield (Table 1). A short-rotation species, such as Sordan 70A, can be harvested as early as eight weeks after seeding. Sugarcane, a long-rotation species, requires at least one year to maximize dry matter. Intermediate-rotation grasses (napier grass, napier hybrids) require four to six months between harvests for optimal biomass yield.

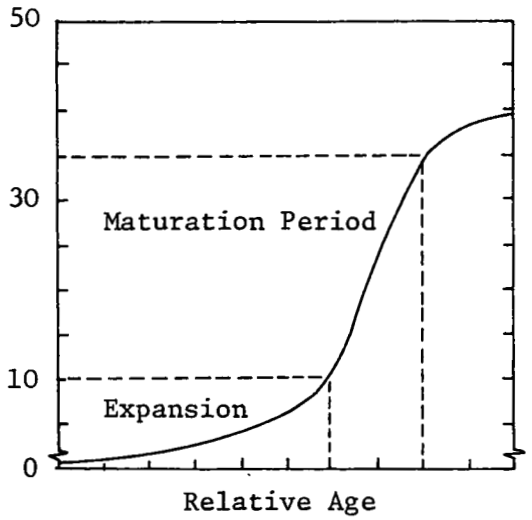
Production and harvest operations for solar-dried tropical grasses under energy plantation conditions are less intensive than conventional forage cropping. Sugarcane harvested six times in 12 months yielded only 3.3 oven-dry (OD) tons/acre, while a single harvest at 12 months yielded 33.6 OD tons/acre (Table 2). Similarly, napier grass harvested twice per year (at 6-month intervals) was more productive than when harvested six times per year (at 2-month intervals) Figure 1 illustrates schematically how biomass yields are increased by delaying harvest of tropical grasses beyond their period of tissue expansion.

Machinery studies for the harvest and solar drying of short-and intermediate-rotation grasses have been generally successful. A short-rotation species such as Sordan 70A represents about 20 standing green tons/acre when mature. Although this material could be cut with a sickle-bar mower under suitable conditions, serious problems are foreseen when it is lodged, matted, and interwoven with weeds. Such materials were quite effectively harvested with a rotary-scythe conditioner. A category III tractor having at least 90 hp is required for this unit. The same implement was also effective on 6-months old napier grass representing about 45 standing green tons/acre. For napier grass the tractor was operated in first gear at an engine speed of 1700 to 1900 rpm. Fuel consumption was about 2.6 gal/hr, or 2.2 gal/acre,

TABLE 2. Grass Yields vs Frequency of Harvest

Harvest Interval	OD Tons/Acre/Yr Cane	Napier
2 Months	3.3	11.9
4 Months	11.9	25.1
6 Months	21.8	33.0
12 Months	33.6	25.8

FIGURE 1. Schematic Curve for % DM Increase in Grasses



with a computed horsepower of 38.7 to 41.4.

Napier grass harvest trials with a Klass whole cane harvester were also successful. The stem billets produced by this machine required more time for solar drying than similar material conditioned by the rotary scythe. A wheel-type forage rake was more effective in windrowing napier grass than a standard rake driven from a power take-off. When solar-dried to 15-20 percent moisture, both Sordan and napier grass were easily baled with a round baler designed for forage grasses. Relatively poor compaction was obtained, however, amounting to 7.5 to 8.5 pounds/cubic foot.

Harvest trials for high-density sugarcane exceeding 90 green tons/acre will be conducted during 1981. Forage-harvest equipment such as the rotary scythe is not suitable for this task. Harvest equipment options for biomass cane under Puerto Rico conditions include: (a) The Klass whole-cane harvester, (b) a modified Klass harvester, (c) the V-cutter with subsequent loader, (d) a V-cutter with continuous loader, and (e), a V-cutter followed by hand loading.

First ratoon yields for sugarcane averaged 88.6 tons of millable stems and 33.6 OD tons/acre year (average of three varieties and two row spacings). Close spacing (50 cm vs 150 cm row centers) did not increase yield. Sucrose yields were quite low, averaging 6.6 percent, but total fermentable solids were comparable to commercial sugarcane in Puerto Rico. At 80 percent extraction approximately 640 pounds of fermentable solids would be recovered from each oven-dry ton of the cane herein described. The highest napier grass yields recorded to date were 91 green tons and 33 OD tons/acre year. These are the combined values of two 6-month harvests.

TABLE 3. Energy Inputs For Cane Production

	Input/Year (x 10^6)	
Item	BTU/A	KCal/Ha
N	13.33	8.30
P	0.60	0.38
K	0.83	0.52
Fuel	8.86	5.52
Pesticides	0.56	0.35
Labor	0.05	0.03
Machinery	3.37	2.10
Seed	0.44	0.27
Total	28.04	17.47

Production costs for sugarcane averaged $25.46/oven-dry ton (about $1.70/million BTUs). Delivery charges for harvested cane, computed at $7.00/ton/three miles of haul, were the highest production cost factor. Energy inputs for production of first-ratoon cane averaged 28.04 mm BTUs/acre year. The energy output was 279 mm BTUs/acre year, computed on a steam recovery basis of 74 percent and assuming 640 pounds of fermentable solids/OD ton removed at the sugar mill. The energy output/input ratio was 9.95/1. While this ratio is generally favorable, nearly half of the total input energy expenditure was for mineral N alone (Table 3). It appears that the energy balance can be improved appreciably by more efficient administration of N fertilizers, or possibly also by use of biological N sources such as tropical legumes.

SECTION 4

WIND ENERGY

WIND ENERGY

Program Chairman: *Edward E. Johanson,* JBF Scientific Corporation
DOE Advisor: *Louis Divone*
Overview Presentation: Tuesday, December 9, 4:00 P.M.

"An Overview Review of Dispersed and Central Wind Systems in the United States" 2-24
Louis Divone, DOE, and *Edward E. Johanson,* JBF Scientific Corporation

SESSION I: Tuesday A.M.

"Department of Energy SWECS Developments" . . . . . *
T. Healy, Rockwell International
"A Status Report on Large Wind Turbine Projects for Generation of Electricity" 4-1
Darrell H. Baldwin, National Aeronautics and Space Administration
"VAWT Technology and Alcoa Vertical Axis Wind Turbines" 4-3
Franklin M. Townsend and Paul N. Vosburgh, Aluminum Company of America
"Economic Modelling of Wind Systems" 4-5
Neil Woodley, Solar Energy Research Institute
"A Utility-Oriented Examination of Test Data from Large Wind Turbines" 4-7
William A. Vachon, Arthur D. Little, Inc.
"National Wind Resource Assessment Methodology" 4-10
Dennis Elliott, Battelle PNW
"Planning of Wind Turbine Arrays" . . . . . *
Peter B. S. Lissaman and Andrew Zalay, AeroVironment, Inc.

SESSION II: Tuesday P.M.

"There's Gold in Them Thar Winds" 4-12
Sterling Munro, Bonneville Power Administration
"PGandE's Wind Development Program" 4-14
James H. Malinowski, Pacific Gas and Electric Company
"A Report on a New Concept" . . . . . *
Ivan L. Gold, Windfarms, Ltd.
"Wind Systems for Island Use – A Utility Perspective" 4-15
Richard E. Bell, Hawaiian Electric Company, Inc.
"Wind Energy Program in Hawaii" 4-17
D. Richard Neill, Hawaii Natural Energy Institute

SESSION III: Wednesday A.M.
Regional Assessment of Wind Energy Systems

"Wind Resource Assessment in the Northeast United States" 4-20
Kenneth E. Pickering and J. Michael Vilardo, GEOMET Technologies, Inc.
"Technical and Economic Feasibility of Wind Turbines in the Northeast United States" 4-22
Robert W. Neal and Martin K. Goldenblatt, JBF Scientific Corporation
"Wind Resource Assessment in the North Central United States" 4-24
Daniel L. Freeman and Donald L. Hadley, ERT/Western Scientific Services
"Wind Energy Resource Assessment for the Great Lakes Region" 4-26
Arthur Bass, Dawna L. Paton and Douglas G. Smith, Environmental Research & Technology, Inc.
"Technical and Economic Feasibility of Wind Turbines in the North Central United States" . . . . . *
R. Carson, Gilbert Commonwealth, and *R. Witholder,* Solar Energy Research Institute

*Abstract not available for printing in Conference Proceedings

Session III (continued)

"Wind Resource Assessment in the Southeast United States" 4-27
Joseph Zabransky, Jr., GEOMET Technologies, Inc.
"Wind Resource Assessment in the Southwest United States" 4-29
Stephen R. Andersen and Donald L. Hadley, ERT/Western Scientific Services

SESSION IV: Wednesday P.M.

"The Technical and Economic Feasibility of Wind Turbines in the Southwest and Southeast United States" 4-31
Donald H. Guild, Stone & Webster Engineering Corporation
"Wind Resource Assessment in the Northwest United States" 4-34
W. Richard Barchet, Pacific Northwest Laboratory
"Technical and Economic Feasibility of Wind Turbines in the Northwest United States" 4-36
Robert W. Neal and Martin K. Goldenblatt, JBF Scientific Corporation
"Wind Resource Assessment in the East Central United States" 4-38
Roger W. Brode and Ronald R. Stoner, NUS Corporation
"Wind Resource Assessment in the South Central United States" 4-40
L. F. Graves, R. Edwards and A. Sprankle, Institute for Storm Research
"Technical and Economic Feasibility of Wind Turbines in the South Central United States" . . . . . *
Orin Merrill, Science Applications, Inc.

SESSION V: Thursday A.M.
Markets for Wind Energy Systems

"Impact of Federal Legislation on Wind Energy Systems" 4-42
Michael Lotker, The Synectics Group
"Preliminary Results of the Rocky Flats SWECS Market Study" . . . . . *
T. Healy and Judith Porpotage, Rockwell International
"Near-Term, High Potential SWECS Market Analysis" 4-44
Martin J. Deutsch, Solar Energy Research Institute
"Estimated Gross Market for Utility-Scale Wind Turbines in the United States" 4-46
Edward E. Johanson, JBF Scientific Corporation
"Regional Marketing of Wind Systems" . . . . . *
B. Sherwin, Enertech Corporation

A STATUS REPORT ON LARGE WIND TURBINE PROJECTS FOR GENERATION OF ELECTRICITY

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National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

For the past several years the Federal Government has sponsored an expanding research and development program to provide renewable energy sources for the generation of electricity, a viable alternative to conventional generation. A major element of the Federal program is large horizontal-axis wind turbine development which is being managed by NASA Lewis Research Center for the Department of Energy. There are several on-going projects within this program element as depicted in Figure 1. In addition, a comprehensive technology program is being conducted in support of these projects. This paper presents an up-to-date overview of these projects with emphasis on utility use of large wind turbines as a supplementary source for electricity.

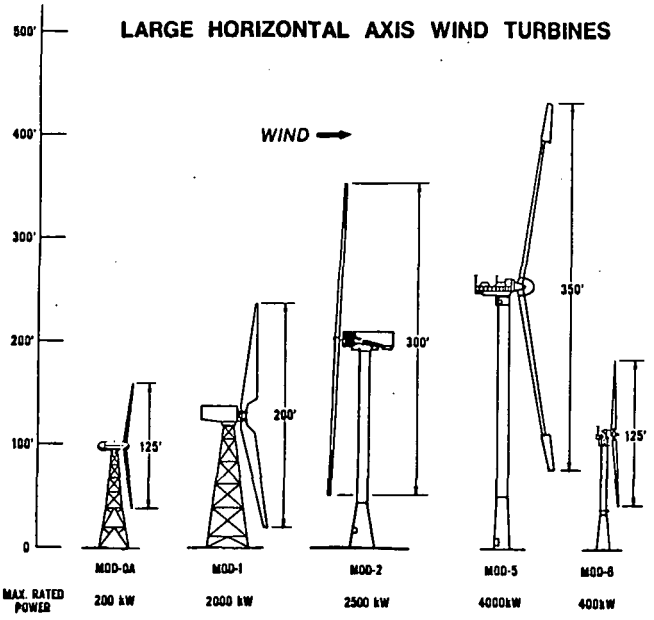


FIGURE 1

First generation wind turbines, called Mod-0A and Mod-1, are shown in Figure 1. These machines have been designed and are now in operation at selected utility sites. The first Mod-0A has been in operation at Clayton, New Mexico since November 1977. During this period the machine has been synchronized to the grid for over 7300 hours during which time it has generated 670 Mwh of electricity. The most recent Mod-0A was placed in operation at Kahuku Hills, Hawaii, in July 1980. Other Mod-0A machines are presently operating in Puerto Rico and Rhode Island. Mod-1, the first megawatt size machine has been in operation at Boone, North Carolina since July 1979. Second generation machines called Mod-2 are presently being installed at Goodnoe Hills, Washington, for testing during 1981. These second generation machines are estimated to generate electricity at less than 5¢ per kilowatt hour (in 1980 dollars) when manufactured at modest production rates. Advanced design machines, called Mod-5 and Mod-6 are currently being designed to meet cost goals of less than 4¢ per kilowatt hour (Mod-5) or less than 7¢ per kilowatt for the smaller size Mod-6 machine. Activation dates for these projects are shown in Figure 2.

ACTIVATION DATES FOR LARGE WIND TURBINES

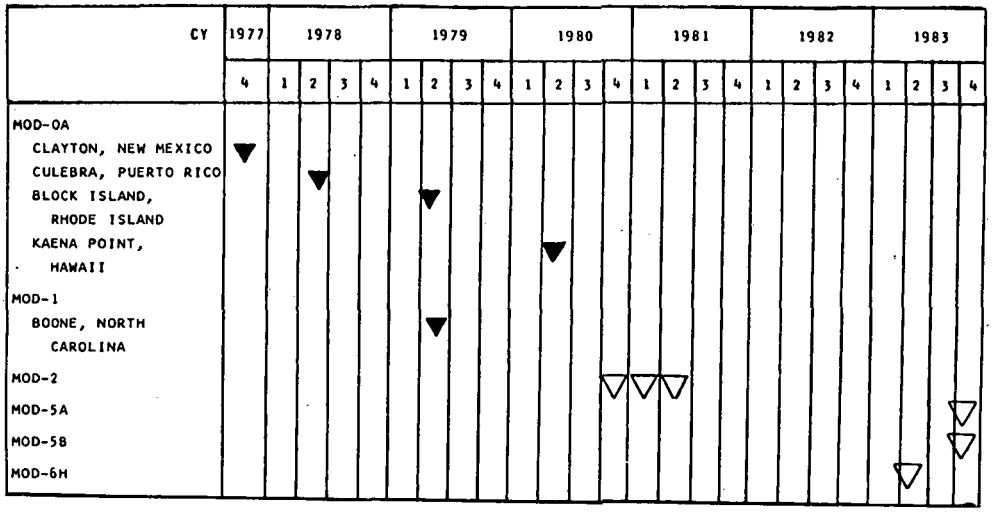


FIGURE 2

Among the attractions of wind turbine systems is the fact that they are for the most part environmentally benign. Only three possible effects have been encountered which have possible important impact on siting considerations. These are television interference,noise, and possibly visual pollution. NASA is currently investigating possible solutions to television interference and noise generation. Aesthetics and limited land intrusion are included as basic considerations in wind turbine design efforts.

In conclusion, wind turbine operations to date have verified the feasibility of the technology and properly designed wind turbines are expected to be environmentally acceptable to the public. Economic estimates indicate that wind turbines can be designed to be cost competitive, and that the amount of electricity that can be generated from the wind is of major significance. Based on large machines such as Mod-2 and Mod-5, conservative estimates place the potential energy savings at 6-7 quads annually. One quad of energy is equivalent to 172 million barrels of oil. Therefore, the Federal government is vitally interested in accelerating and encouraging the near-term development of safe, reliable, and cost effective wind turbines.

VAWT TECHNOLOGY AND ALCOA VERTICAL AXIS WIND TURBINES

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Aluminum Company of America (Alcoa) is developing and testing an introductory line of Vertical Axis Wind Turbines which have been designated ALVAWTS.TM This paper describes those machines, discusses Alcoa's development and commercialization efforts, and provides data for three models which are believed to be cost effective for use today at sites with mean annual wind speeds in excess of 6.3 m/s (14 mph).

The features of the modern Darrieus-type Vertical Axis Wind Turbine were patented in France in 1925 by G.J.M. Darrieus and additional patent protection was granted in the United States in 1931. Although the Darrieus invention covered several versions, the fixed-pitch, curved-blade approach with both ends attached to a rotating vertical tower represents today's generic "Darrieus Turbine." Its distinguishing feature is the special shape of the blade which is represented by the Greek word "troposkien" meaning turning rope. By forming the blades into that shape, major stresses are expected to be in tension when the rotor is spinning. Aerodynamic lift from the blades provides driving torque regardless of wind direction. The VAWT regulates automatically at high wind speeds, so no feathering device is needed to keep the turbine from producing more power than its rated capacity.

In the 1960's, the National Research Council of Canada initiated a program to further develop and demonstrate Darrieus-type Vertical Axis Wind Turbines and their efforts led to the installation of over two dozen turbines, including several in the United States, with the largest having a generating capacity in excess of 200 kW.

The United States effort in Vertical Axis Wind Turbines began in 1973 at Sandia Laboratories in Albuquerque, New Mexico. Two research machines are now in operation at Sandia's test site. The smaller has a rotor with height and diameter of 5 m (15') with 15.3 cm (6") chord aluminum airfoil blades and is sometimes referred to as a 5 kW Vertical Axis Wind Turbine (VAWT). The larger has a rotor height and diameter of 17 m (55') with 61 cm (24") chord Alcoa blades and is sometimes called a 60 kW VAWT. The productive Sandia Laboratories efforts are directed and funded by the U. S. Department of Energy.

After investigating the history and the state-of-the-art of Wind Energy Conversion Systems, Alcoa decided in 1976 that the advantages of Vertical Axis versus Horizontal Axis Wind Turbines, as well as a good fit between available VAWT technology and Alcoa resources, offered the best opportunity for development of cost-effective, low-maintenance, performance-reliable wind conversion hardware. Today, three ALVAWTS are being offered on a controlled basis--ALVAWT Models #835524-120 kW, #1238229-300 kW and #1238229-500 kW. In addition, work has been initiated on the development of a megawatt scale turbine.

All of the Alcoa machines utilize induction generators which must be interfaced with, and started and synchronized by, outside three-phase electricity such as available from most utility grids. None is for residential use. None is for use on a "stand-alone" basis. Energy output is 60 Hz, AC. No storage or power conditioning is needed.

The evolution of Alcoa research and development efforts to develop a line of VAWTS included prototyping of 8 kW and 57 kW research machines and a conclusion that those sized machines could not be made cost effective in the near term. Much was learned from the destruction of an Alcoa Laboratories prototype of a two-bladed 63' x 42' rotor on 1980 March 21 at Alcoa Center, Pennsylvania.

ALVAWT Model #835524-120 kW evolved from an Alcoa Laboratories contract with DOE to design and build four prototypes of a low cost version of the Sandia Laboratories 17 meter research VAWT. The first of those four units was installed at the Rocky Flats, Colorado, SWECS test site in 1980 August and the second was delivered to the USDA Agricultural Research Center in Bushland, Texas in November. The remaining two were fabricated and will be installed at DOE sites this winter.

ALVAWT Model #1238229-300/500 kW was developed at Alcoa's expense by Alcoa Laboratories and a prototype of the 300 kW (35 rpm) version was installed at Alcoa Center in 1980 June and, after elaborate instrumentation, has been researched and tested since then.

ALVAWT Model #1238229-500 kW has been installed near Agate Beach, Oregon, as part of an American Public Power Association research project. The Project Manager is Eugene Water and Electric Board and the host utility is Central Lincoln Public Utility District. Most publicly-owned utilities in Oregon are participating.

ALVAWT Model #1238229-500 kW is also part of a research project by Southern California Edison at their test site in San Gorgonio Pass near Palm Springs.

The objective of the research projects is to get "hands-on" experience with the machines under real-world conditions. Delivery, installation and start-up procedures will be refined, and cost estimates as well as performance projections will be confirmed or revised. Perhaps most importantly, the ground work will be laid for the ultimate question--"How many machines do you have up, how long have they been operating, and how have they performed?"

PERFORMANCE SPECIFICATIONS

ALVAWT Model	Target Wind Regime	Projected Energy Generation (kWh) @ 14 mph	@ 16 mph	@ 18 mph	@ 20 mph
#835524-120 kW	14-18 mph+	195,000	280,000	350,000	420,000
#1238229-300 kW	14-17 mph	475,000	680,000	865,000	1,040,000
#1238229-500 kW	17-21 mph+	510,000	725,000	1,125,000	1,275,000

Operating Range: 12-60 mph Design Survival Winds: 150 mph Gusts

In simplistic terms, the investment per annual kWh generated in wind regimes of 14-24 mph ranges from a low of $.20 to a high of $.80, with no allowance for tax credits. If an application appears to have promise, Alcoa will welcome the opportunity to explore it in detail. With the right combination of available wind resource and competitive fuel or electricity cost, available ALVAWTS can start providing energy and cost savings now.

For further information: Paul Vosburgh, 412/339-6651; Frank Townsend, 412/553-3824

ECONOMIC MODELING OF WIND ENERGY STUDIES

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There are many different classes of modeling/simulation efforts completed in the literature, in progress and planned for the assessment of wind energy systems. These include system operating and system planning performance modeling; machine and system design modeling; impact modeling including noise generation, propagation and impact effects and TVI and RFI impact effects; and economic modeling. This paper will focus on the latter class, however some of the more important links to the other classes that have been developed recently will be discussed. Accurate and credible economic models are essential to the accelerated diffusion of wind energy conversion systems (WECS) into the energy consuming end use sectors of the economy. Wrong assessments and faulty analyses have resulted in embarrasing and negative reactions to the emerging WECS industry.

Two elements emerge as common to all WECS economic models: cost and value.

Cost Representation

To develop costs of WECS three major elements are necessary: manufacturing costs, construction costs, and operation and maintenance costs (O&M). Manufacturing costs relate to the actual fabrication of the wind turbine and associated subsystems; construction costs include the design, construction and installation of the system; and O&M covers the costs associated with the turbine operations and maintenance over the useful lifetime of the equipment. All three costs are necessary to develop "life cycle" costs of WECS.

A major difficulty with current manufacturing costs is that WECS are not presently manufactured on a large volume basis. Therefore mass production and automation techniques are not used and costs of the turbines are based on "learning curve" models derived from other mass production experiences. Detailed manufacturing cost assessment of wind turbines is useful to (a) define potential costs under mass production scenarios; (b) identify design cost drivers; and (c) provide information about capitalization requirements to wind turbine manufacturers for use in developing business plans. SERI is currently performing such studies. Similarly, better evaluations of construction cost components are underway to include site development, equipment installation, foundations, transportation, and field labor requirements. Very little is currently known about O&M costs of modern WECS and their effect on life cycle costs.

Value Representation

"Value" has been substituted for "benefit" in the previously familiar cost/benefit ratio determination of project viability to more narrowly focus the meaning. Potential benefits of WECS not captured in the value calculation include: labor intensive, decreased fuel imports, fuel reserves, fuel diversity, environmental, technology transfer, and secondary economics.

Value analyses for WECS can generally be viewed as from the perspective of the electric utility to which the machines may supply electric energy on an intermittent

basis or from the perspective of the non-utility end user/owner. Quite different economic models result. The utility view of value of WECS evaluates both central station "dusters" and distributed installations with the aid of an hourly WECS performance model, a load model, and a utility generation system production cost and reliability analysis model. For the distributed case, studies have been completed that include transmission and distribution system effects as both capacity and energy (loss) credits.

The value of WECS to the end user is quite a different economic model. The hourly WECS performance model is used but in conjunction with existing electric energy rate data to calculate the value of the WECS to the user based on the reduction in the customer's monthly electric bill. Sellback rates are typically treated parametrically. There are two major problem areas associated with end-user economics assessments of WECS: (1) the relationship between electric rates and the host utility's cost to serve, and (2) characterizing the economic circumstances and decision processes of the end users. These end users may include residential, commercial, industrial and agricultural sectors, each with vastly different decision criteria.

Relationship Between Electric Rates and Utility's Cost to Serve

Existing rates for most electric utilites are generally based on average, non-time differentiated accounting costs. Thus, they reflect neither the short-term fuel costs nor the long-term marginal costs that the utility incurs in serving its customers. The problem with using current rates based on average costs to assess the value of wind turbines is that existing rates are likely to be changed in the future.

The Public Utility Regulatory Policies Act (PURPA) of 1978 calls for rate reform in two areas that will have a major impact on the economic feasibility of WECS owned by end-users. Title I requires utilities and public utility commissions (PUCs) to consider adopting retail rates that more adequately reflect the utility's cost of providing electric service. Section 210 of PURPA requires utilities to purchase power from qualifying facilities (which include wind turbines) at rates equal to the utility's full avoided cost. Specifically, utilities must pay qualifying facilities at rates that equal the energy and capacity costs that the utility would have incurred without the energy purchases from the qualifying facilities. The Federal Energy Regulatory Commission issued the final rules implementing Section 210 of PURPA in February and March 1980. Utilities and PUCs must begin implementing those rules in March 1981.

Characterizing the Economic Circumstances of End-Users

There are two major problems associated with assessing end-user applications. The first relates to selecting the proper discount rate, and the second is the need to represent the user's other investment options.

The discount rate is one of the most important parameters that must be identified in assessing the relative cost of different energy systems. For example, comparing the cost of a wind turbine to the cost of electricity purchased from a utility involves comparing a major capital investment to a series of monthly payments. In order to put the two different cost streams on a consistent basis, they must be weighted or discounted. Defining the correct discount rate is critical because, for this example, the higher the discount rate, the higher the present value of the cost of the wind turbine relative to the cost of purchasing electricity.

A UTILITY-ORIENTED EXAMINATION OF TEST DATA FROM LARGE WIND TURBINES[+]

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Project Description

The Electric Power Research Institute (EPRI) is sponsoring an ongoing project with the goal of assessing and communicating key results from large wind turbine (WT) generator tests to the electric utility industry. The WT's are rated $\geq$ 100 kW. This assessment will provide a succinct summary and analysis of data, data trends, and key case studies from installations in which large WT's are interconnected with electric utilities.

This project has been evaluating the test performance of both the U.S. Department of Energy (DOE) large WT's and those being developed with private funds. The DOE WT test data evaluated thus far have emanated from programs being managed by the NASA Lewis Research Center (LeRC) for the development of large, horizontal-axis wind turbines (HAWT's). At the present time, the DOE vertical-axis wind turbine (VAWT) development program is being managed by the Sandia Laboratories. The VAWT's tested thus far have been of the Darrieus design with power outputs of less than 100 kW.

Project Content

Table 1 lists the large WT test programs that are being followed. The data from these programs are being examined, as they become available, with key results communicated to the electric utility industry. As described in the footnote to Table 1, this project is studying five machines that are being developed with private funds.

Table 1. LARGE WIND TURBINES STUDIED

Manufacturer	Type	Rated Power (kW)
Alcoa	VAWT	500*
Bendix/Wind Power Products	HAWT	3,000*
DAF-Indal	VAWT	224
General Electric	HAWT	2,000 (MOD-1)
Hamilton-Standard	HAWT	3,000
Mehrkam Energy Development Co.	HAWT	45* & 2,000*
Westinghouse	HAWT	200 (MOD-0A)
WTG Energy Systems, Inc.	HAWT	200*

*Privately funded.

[+]Work supported by EPRI under contract RP1348-1.

Example Results

Results to date have been summarized in two reports[1,2] which are available from EPRI. Thus far, the vast majority of the reported test results have emanated from federally funded programs. However, in late 1980 and early 1981, a number of privately funded large WT tests will come on line and should begin to provide valuable test data. These tests are expected to involve large machines from Alcoa, Bendix, Mehrkam Energy Development Company, and WTG Energy Systems, Inc. A summary of their machine designs and plans is found in Reference 2. These experiments will be monitored in the future as part of this project.

The DOE/NASA large WT test program has accumulated more than 11,000 hours of operating time on the six test machines listed in Table 2. The last five WT's listed were interconnected with local electric utility systems when operating. The machines listed are all first-generation designs; that is, each has a rigid truss tower and a downwind rotors as opposed to a cylindrical tower and upwind rotor planned for the next generation design. Also, these past designs did not include a teetered hub, which will be found in the next generation design (viz., MOD-2). The first generation WT's are all being used as engineering and research machines, and as such, may experience frequent outages because of their experimental nature. However, electric utilities would like to know how these machines would behave if they were employed in their service areas, while being operated and maintained as a piece of normal generation equipment.

Table 2. ACTIVE DOE/NASA TEST WIND TURBINES

Machine Description	Location	Activation Date	Hours of Operation[+]
MOD-0 (100 kW)	Sandusky, Ohio	9/75	~1,000
MOD-0A (200 kW)	Clayton, New Mexico	3/78	7,333
MOD-0A (200 kW)	Block Island, Rhode Island	10/79	945
MOD-0A (200 kW)	Culebra Island, Puerto Rico	1/79	1,310
MOD-0A (200 kW)	Oahu, Hawaii	5/80	638
MOD-1 (2,000 kW)	Boone, North Carolina	9/79	>200

[+]As of 7/31/80.

In order to examine this issue, the WT test data and lost operating time that could be attributed to the research nature of the equipment were filtered from the overall test results. The reasons for lost WT operating time were examined and estimates for the expected outage time were made as if the WT were a non-research machine. Data from the Clayton, New Mexico, MOD-0A WT were employed in the analysis. In many cases, the estimated period of outages was reduced to a small fraction of the measured time. During the analysis, prolonged outages due to blade repairs and generator mechanical problems were omitted, because they are expected to be largely alleviated in future designs. Furthermore, it is expected that most spare parts will be on hand for quick repairs.

The results of the analysis for a 74-week period, shown in Figure 1, indicate that the machine availability[1] of a non-research machine averaged approximately 7 percentage points above that of a research machine and at a constant level of 89 percent. The availability of the research machine has, however, improved with time as research and engineering problems were solved.

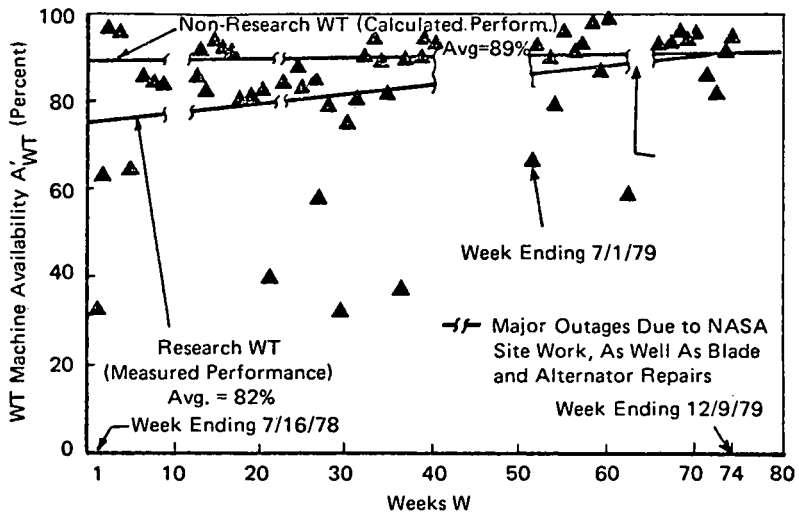


Figure 1. CLAYTON, NEW MEXICO WT AVAILABILITY IF EMPLOYED WHOLLY FOR ENERGY PRODUCTION AS A NON-RESEARCH MACHINE

Future Plans

This project will continue to examine future large WT test data in a manner that will provide the electric utility industry with significant information. In future phases of this project, increased emphasis will be placed on privately funded WT's. Another thrust of this project will be to develop information associated with WT/network interactions and suggest approaches to measuring these interactions.

References

1. Vachon, W., "Large Wind Turbine Generator Performance Assessment, Technology Status Report No. 1," EPRI Report AP-1317, January 1980.

2. Vachon, W., "Large Wind Turbine Generator Performance Assessment, Technology Status Report No. 2," Report to the Electric Power Research Institute by Arthur D. Little, Inc. on EPRI Project RP1348-1, 1980.

NATIONAL WIND RESOURCE ASSESSMENT METHODOLOGY

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Twelve regional wind energy resource atlases, covering the United States and its territories, have been produced. These atlases, products of the Wind Characteristics Program Element of the Federal Wind Energy Program, represent major sources of information for those seeking information on the wind energy resource. To ensure that the regional atlases are comparable, the prototype techniques developed by Pacific Northwest Laboratory (PNL) have been applied, with only minor deviations, to all regions. These techniques, described in greater detail by Elliott and Barchet (1980), included identification of wind data sources, screening and evaluation of wind data, the use of qualitative wind indicators, construction of wind power maps, the assignment of certainty ratings, and the estimation of the areal distribution of the wind resource. Moreover, the presentation format of the text, maps, and graphs is essentially the same for all of the atlases.

Each atlas includes a description of the methodology and a summary of region's features (e.g., geography, climate, average wind power, and major wind resource areas), followed by more detailed descriptions and maps for each state or subregion. Graphs of the wind characteristics (e.g., interannual, monthly, diurnal, etc.) are presented for selected stations in each state.

The surface wind data used in the assessments were obtained from various sources: the National Climatic Center (NCC), the U.S. Forest Service, universities, utilities, and other government and private organizations. The National Climatic Center offered the largest collection of wind data. Surveys and indices of wind data archived at the NCC were extremely helpful in locating available wind data. Screening procedures were developed to identify stations with the most useful data and to eliminate stations that would not significantly contribute information on the distribution of the wind resource. Wind data in summarized or digitized format were chosen over unsummarized data.

For the purpose of mapping the geographical variation of the wind resource, wind power density was chosen over wind speed since the power density incorporates in a single number the combined effect of the distribution of wind speeds and the dependence of the power density on air density and on the cube of the wind speed. Quantitative wind data in three formats were evaluated for mean wind power density: digitized, summarized, and unsummarized. A power law exponent of 1/7 was found to be widely applicable to low surface roughness and well-exposed sites from which conventional NCC data are available and was used to adjust the mean wind speed from anemometer height to the reference level. For over 1000 stations with one- or three-hourly data on NCC magnetic tapes, PNL prepared detailed summarizations of the wind characteristics that were provided for use in each region's assessment.

Techniques and data bases for estimating the mean free air wind power over mountain summits and ridge crests varied somewhat from region to region. However,

(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

in all regions the mean wind power at the 10-m and 50-m reference heights was taken to be one-third and two-thirds of the free air value, respectively, to account for the frictional slowing of the wind near the surface. These estimates are considered lower limits for exposed ridge crests and mountain summits.

To evaluate the distribution of the wind resource in data-sparse areas, three qualitative indicators of wind power were developed for use in the assessments. The most widely used technique involved the identification of certain features of the topography and climate that are indicative of high or low wind power. Wind-deformed vegetation and eolian landforms also served as indicators of wind power in some data-sparse areas.

The analysis of the wind power maps departs from conventional isopleth analyses by showing the boundaries of wind power density classes. Table 1 gives the power limits for the wind power classes used in the atlases for the 10-m and 50-m reference levels. The wind power maps apply to terrain features that are favorably exposed to the wind. In forested or wooded areas, the assessment values are representative of large clearings, such as airports, with good exposure to the prevailing strong winds. Maps of land-surface form provided information on the distribution of plains, tablelands, hills, and mountains. For each class of land-surface form, the exposed features to which the map values pertain are specified.

The areal distribution of wind power is estimated by considering the percentage land area that is well exposed, moderately exposed, and poorly exposed in each land-surface form. Certainty ratings of the wind resource estimates have been developed by considering the availability of wind data, the complexity of the terrain, and the inherent spatial variability of the wind resource. The areal distributions and certainty ratings have been presented for each cell of a one-quarter degree latitutde by one-third degree longitude in the 48 contiguous United States. Different sized grid cells were used in the other regions. In each of the atlases, areal distribution maps give the percentage land area in a cell over which the wind power class equals or exceeds threshold values of classes 2, 3, 4, and 5. For each state and region, a summary table gives the estimated land area (km^2) and percentage land area associated with each power class.

TABLE 1 Classes of Wind Power Density at 10 m and 50 m[a]

Wind Power Class	10 m (33 ft) Wind Power Density, watts/m^2	10 m (33 ft) Speed,[b] m/s (mph)	50 m (164 ft) Wind Power Density, watts/m^2	50 m (164 ft) Speed,[b] m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.
(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

Reference

Elliott, D. L. and W. R. Barchet. 1980. Techniques for Assessing the Wind Energy Resource Over Large Areas. PNL-3360, Pacific Northwest Laboratory, Richland, WA.

THERE'S GOLD IN THEM THAR WINDS

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The three largest wind energy machines ever built anywhere in the world are going up on the banks of the Columbia River near Goldendale, Washington, in a joint test program of DOE, NASA, Boeing and the Bonneville Power Administration (BPA).

Nearby, in Klickitat County, Washington, BPA is installing 12 family-sized windmills.

Meanwhile, for the past 4 years, with the help of Oregon State University's Department of Atmospheric Sciences, BPA has been gathering data on more than 50 wind sites and has identified 8 prime sites, including the Klickitat County area.

The purpose of this paper is to describe each of our major wind projects and our regionwide wind energy assessment efforts.

Electricity from the three giant wind machines will be integrated into the Federal Columbia River Power System (FCRPS). BPA markets the power for this system which includes 30 hydroelectric plants with a total capacity of nearly 18,000 mW. This hydro system provides an ideal storage facility that will allow BPA to smooth out the production of electricity from such intermittent sources as the wind. BPA cannot store the electricity produced by wind turbine generators (WTGs). But we can store water in the reservoirs behind the dams by holding back part of the flow of the rivers while the WTGs are operating. When they shut down, the stored water can be released through turbines in order to generate electricity.

The three big wind machines are the MOD-2 design built by the Boeing Engineering and Construction Company, each with two blades 150 feet long and a turbine generator mounted on a 200-foot tower. The MOD-2 machines start operating at windspeeds of 14 mph and feather out at 46 mph. At windspeed of 27.5 mph and above each will generate 2.5 megawatts (mW) of power. The combined capacity of 7.5 MW is enough to serve the needs of about 2000 typical Northwest households.

The first MOD-2 unit at Goldendale, scheduled for operation in December 1980, cost $5 million. The other two machines, due on line in March and June 1981, respectively, will cost about $4 million each. The first is expected to produce 8 to 9 million kWh annually at 8 to 10 cents per kWh. Cost of electricity from MOD-2 machines is expected to decline to about 4 cents per kWh when and if the machines are mass produced.

An evaluation of the MOD-2 will include electric stability; disturbances to the transmission system; correlation of wind, power, and energy; hourly energy production and annual capacity factors; operating characteristics; wind-hydro resource integration; economic studies; resource planning; impacts of storms on WTGs, and electromagnetic interference and mitigating measures.

The dozen family-sized small WTGs BPA is installing in Klickitat County are expected to produce 15 to 35 percent of the average energy needs of an all-electric Northwest home. Each small WTG is connected to the local PUD system through home or farm wiring systems. Meters record energy output, hours of service, energy supplied to the property owner, etc. These machines have a capacity of 2-to-4 kW and cost from $5,000 to $15,000 each. The basic objective of the small WTG program is to verify manufacturers' estimates of energy production. They range from 3,400 kWh/yr. for a 2-kW machine on a site where the wind averages 10 mph to 9,000 kWh/yr. for a 4-kW machine on a site where the wind averages 12 mph.

BPA's wind data gathering effort has covered about one-third of our 300,000-square-mile service area, which includes Oregon, Washington, Idaho, and part of Montana. The wind assessments cost about $10 per square mile and take about 5 years to complete for each potential site. About one percent of the total area has been identified as having prime wind conditions. We estimate the cost for a more comprehensive evaluation of these prime areas to range from $5,000 to $10,000 per square mile.

Of the 8 prime areas we have identified, 5 are in or near the Columbia River Gorge. The others are widely dispersed over the southern half of the region. Six general areas appear suitable for wind farms with a total of about 1,000 2.5-to-4-MW WTGs.

We have been measuring the winds at the Goldendale site for 3-1/2 years. They blow year round and are strongest from February through September. They average about 16.5 mph and blow between 14 and 45 mph about 53 percent of the time -- above 15 mph 55 percent of the time, above 25 mph 25 percent of the time, and above 45 mph 2 percent of the time.

The task of gathering wind data recently became easier when low-cost, battery-powered, solid-state recording devices became available. This equipment can be set up anywhere in a weather-tight box. It will record data in sub-zero weather.

BPA has pioneered the use of other low-cost equipment such as the tethered aerodynamically-lifting anemometer (TALA) kite. The kite is useful for obtaining vertical wind profiles.

When integrating wind energy, planners for the electric system must allow for the variable and unpredictable nature of winds as well as severe climatic conditions that may impact WTGs. Nonetheless, we believe that the Federal hydro system can be used to "shape" a variable resource such as wind. By this we mean the system can deliver power when needed to conform to a utility's load. We hope to demonstrate this and thereby show that winds can be mined forever.

PGandE's WIND DEVELOPMENT PROGRAM

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Based on the preliminary assessment of the wind resource in the PGandE service area, the potential for favorable power costs from large wind turbine developments, and other benefits that may be derived from developing a renewable resource, PGandE is including wind in its current generation resource plan.

PGandE plans to install a large horizontal axis wind turbine by January, 1982 to demonstrate the technical and economic feasibility of the particular turbine selected and to gain operating experience on the system. The site and turbine will be selected in September, 1980.

An additional 80 megawatts of wind are scheduled to be installed by 1990. These resources are included in the basic resource plan which shows a development scenario that appears most likely based on existing information. In addition to the basic plan, parallel path resource options have been developed which include projects that could come on line if successful demonstration occurs, the wind resource is proven, economics appear reasonable, and other obstacles are overcome. These scenarios do not set a limit on development and are revised every six months to reflect results of on-going RD&D both within and outside the Company.

In June, 1980, PGandE embarked on a two-year, $1 million wind measurement program to confirm the results from an earlier prospecting program. The program is designed to result in wind data of sufficient detail to be of value in the siting of wind turbines. The two instrumented areas are in Solano and Alameda counties. Siting studies are also being conducted. A siting methodology has been developed and includes the evaluation of wind resource characteristics, land use planning, environmental concerns, geology and land acquistion.

The resolution of economic and reliability issues will assist decision-making in planning large wind installations. The issues include the cost of power from wind energy, the financial risk for early windfarm developments, and the integration of wind systems into the utility grid. Current information on PGandE's activities in these areas will be presented.

WIND SYSTEMS FOR ISLAND USE - A UTILITY PERSPECTIVE

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Many first-time visitors to Hawaii express surprise at the consistent and strong winds that sweep over the island chain. We owe it to poets and writers of south-sea novels for the concept of soft, gentle trade winds. While the sound of rattling palm fronds may be keeping some people awake at night, assuredly the trades are a blessing. Any doubt on the score can be quickly settled if one is here on a day there is no wind. Thus, those who live here have long recognized the value of our natural air conditioner; hang gliders and soaring records are regularly set here, and kite flying is unexcelled; and even one large resort hotel had to radically overhaul its entry because of the wind. But, recognizing that the wind was not an unmixed blessing and planning to put it to use generating electricity are quite different things. This paper will describe how it is that Hawaiian Electric has become actively interested in wind as a source of electric energy.

Hawaiian Electric Company (HECO) supplies 97% of the electric energy consumed in the State of Hawaii. Virtually 100% of the energy the Company generates comes from residual fuel oil or diesel fuel oil, and 10% of the energy the Company distributes comes from biomass and hydropower.

The HECO electrical system serves the islands of Oahu, Maui, and Hawaii. None of these islands is interconnected, each depending solely upon its own system for electrical power.

Historically, the State of Hawaii is six months younger than the State of Alaska. However, geologically, Hawaii is millions of years younger. Thus, no petroleum lies beneath the islands, and the oil which has kept the electric lights on in the middle of the ocean for the last 80-odd years arrives by tanker. Oil-burning, base-load power plants are extremely reliable machines; however, they consume a lot of oil. HECO's consume about 30,000 barrels of oil a day--a consumption rate that will inevitably increase unless it can find reliable alternatives at a reasonable cost.

Oil has increased in price by more than a factor of 8 during the past few years. The cost of oil is now more than one-half the total cost of electricity. At the end of this month, HECO will begin buying oil under new long-term contracts. Thus, December spells the end of ten years of fuel oil purchases under very favorable conditions negotiated when oil was about an eighth of its present cost. Beginning January 1, the typical residential bill will increase about 42%. This is just one of the reasons for continually seeking alternatives to the expensive fuel oil diet of the power plants.

HECO's policy is to pursue all alternative energy programs that are perceived as being capable of yielding a reliable source of electrical energy in a timely and economically viable manner. Currently, it is active in fields as diverse as

biomass, OTEC, geothermal, solar, and wind. An element common to all these alternatives is risk, and risk is anathema to an industry noted for its conservatism in many areas--an industry from which society has come to expect 100% reliability and stability. Since wind is not noted for its reliability and stability, how then can HECO be actively interested in it?

To begin with, a wind farm is an untried energy source, blessed with unknown costs, a paucity of information on stability, and with a reliability factor dependent on such things as machines that have not been manufactured. Despite this, there is wind, and, while wind energy at this time cannot be considered as base or firm energy, if a wind farm can generate kilowatthours, then we have at least started in the direction of reducing our oil consumption. That is, wind energy today is an oil replacer--it may replace generating capacity at some point in the future.

In order to encourage the development of the first large-scale wind farm now in the planning stage and to be connected to HECO's system near Kahuku on the northern tip of Oahu, HECO negotiated 25-year energy-purchase contracts. HECO guarantees to purchase all the energy produced, with a minimum price guarantee and the price based on its average fuel cost.

This arrangement allows a private company to enter a new field with a guaranteed customer and price for all of the product it produces. With all the benefits taken for energy tax credits and assuming reasonable luck with the wind turbine generators (WTG), this 80 mw, 20 to 30 WTG project appears to offer the developer sufficient return for his risk and gives HECO a source of electric energy at a slight cost advantage to the ratepayer.

However, HECO does not see its role as being merely a distributor of electricity generated by the wind. HECO will operate and maintain the wind farm and interconnection facility and will have an option to buy the facility. HECO will become owner of wind energy facilities as soon as it finds that the technology has matured to the point that the business risks and costs are compatible with the return permitted by the regulated nature of our business. However, beyond the belief that HECO should manufacture as well as distribute energy is another reason for our interest in owning the facilities. Under the provisions of the Public Utility Regulatory Policies Act of 1978 (PURPA), the price paid by HECO to a small power producer can be as much as HECO's avoided costs. Since HECO is an oil-burning utility, this means that the cost of oil sets the price for energy it purchases from another source. The price of oil is not based on costs to manufacture it, or upon reasonable returns; it is determined by OPEC. Thus, our ratepayers face the prospect of having their electricity generated by an alternate source owned by a small power producer but having the cost of it determined by the cost of oil. On the other hand, if HECO owns the facility, its rates, approved by the PUC, are functions of its costs. HECO believes that the ratepayers will realize the greater savings coming from alternate energy sources when those sources have been incorporated into the utility system.

WIND ENERGY PROGRAM IN HAWAII

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INTRODUCTION

Just two years ago, the Hawaii Natural Energy Institute (HNEI) held a conference entitled "Wind Energy - Here and Now." Although the title and most of the speakers were rather optimistic about wind energy potential in Hawaii, reservations were expressed by many participants on wind providing any significant near term contribution of electric energy to the utility grid.

Today, only two years later, with the cost of oil more than doubled and with exciting advancements in the development of wind energy conversion systems (WECS) hardware, our energy community is seriously looking to wind to provide up to 10 percent of Hawaii's electrical energy by the mid-80s.

The Hawaii Natural Energy Institute's Wind Energy Application Network (WEAN) Program is being developed to accelerate the contribution of wind energy to "wean" Hawaii from our current 90 percent dependence upon imported oil. Many problems must be addressed and resolved if this ambitious goal is to be achieved. This paper will summarize briefly Hawaii's wind goals, potential, and programs.

GOAL

Wind advocates in Hawaii suggest a goal for 1990 of 30 percent of Hawaii's electrical energy to be provided by wind energy conversion. How closely this goal is achieved certainly will not be limited by the potential wind resource throughout the State, but will be contingent upon the rate of development of reliable WECS, the adaptability of wind farms to power grid system integration, the availability of investment capital, and other socio-economic factors. Should the ambitious 1990 goal of 30 percent of the electrical energy from wind energy conversion actually be realized, this would provide 2.9 billion kwh annually and would replace some 5 million barrels of imported oil valued from $300 million to $450 million, depending upon whether you prefer an estimate of $60 or $90 per barrel of oil in 1990. Thus, only about three years of fuel oil savings would provide the capital necessary to cover the probable cost of this WECS investment.

POTENTIAL

Hawaii's excellent wind regimes, well documented by the UHM Department of Meteorology, are the basis for these optimistic projections. Northeasterly trade winds blow over 70 percent of the time and the islands' mountain ranges funnel them through valleys and across isle corners to produce wind speeds from 16-28 mph in many areas.

HNEI has just published a Report for Wind Energy Programs in Hawaii, which includes excerpts from the Wind Atlas for Hawaii and the Pacific Islands by UHM Department of Meteorology and which projects reasonable sitings for four typical WECS [two large megawatt WECS (Boeing and Hamilton Standard); one small 70 kw

(Kaman) WECS; and one 300 kw VAWT (Alcoa)]. Calculating WECS sites at distances of three blade diameters across the wind direction and ten blade diameters down wind from each other results in a total wind potential at the primary wind sites in Hawaii (Kahuku, Oahu; Northwest Hawaii; Central Valley, Maui; Northwest Molokai) which greatly exceeds the total electrical energy requirements for the state.

WEAN PROGRAM ELEMENTS

To achieve the optimum usable energy from this great potential, HNEI's WEAN (Wind Energy Application Network) Program includes the following elements.

A. WIND RESOURCE ASSESSMENT

The UHM Department of Meteorology has carried on an extensive wind characteristics program over the past six years, documenting mean annual wind speed averages ranging from 16 to 28 miles per hour (@ 50 meters) over 1/10 of Hawaii's land area. HNEI's wind resource assessment program will make possible continued wind data collection to evaluate thoroughly Hawaii's wind energy potential and intense site-specific wind monitoring to help site WECS and wind farms. Nineteen meteorological towers (30- and 150-foot), four mobile wind stations, twelve high altitude TALA kites, and twenty wind data accumulators (WDA) have been purchased for monitoring purposes. Recent activities have included Kite Week at Kahuku, Oahu, in August where four mobile vans with 30-foot masts and kites flown at 100 feet and 500 feet collected continuous data at 2 second intervals, and establishment of a wind data accumulator loan program. Those who wish to install a WECS can borrow a WDA, collect short term wind data at their site, compare it to data from the nearest long term reference station, and estimate their annual kwh values for a given WECS. All available data and all new information collected by this wind characteristics monitoring program will be stored in the Wind Data Bank, which will be used for wind research as well as for WECS siting.

B. WIND ENERGY APPLICATION RD&D

Demonstrating WECS capabilities for specific applications is necessary if wind potential is to be fully realized. This part of Hawaii's WEAN Program will make core staff available to help with various wind energy RD&D projects in the state.

HNEI currently is involved in RD&D for (1) wind energy-nitrogen fertilizer production utilizing an electric arc; (2) wind-water pumping with an innovative device developed to increase the stroke and value of water pump nearer the cube function of the wind speed; (3) a wind-agricultural irrigation market plan; (4) wind-battery storage (design and implementation); (5) a wind-acoustic study of installed WECS; and (6) a corrosion center to study wind equipment corrosion control methods for Hawaii. Other applications include use of wind for thermal and electric applications including power for electric vehicles.

C. WIND TESTING, EVALUATION, APPLICATION AND MONITORING (TEAM) PROGRAM

Hawaii's superior wind regimes provide optimum conditions for government program staff, wind energy users, and WECS manufacturers to work out technical problems on long term on-line operations in a relatively short period of time. Thus, the TEAM Program will test, monitor, and evaluate WECS by siting new machines, instrumenting them, and analyzing results. As part of a wind energy applications network in the state, a WEAN Center will be established on Oahu with satellite stations on each major island to coordinate efforts. Those WECS which are scheduled to be up and operating in Hawaii by Conference time include: U.S. DOE MOD-OA,

Merhkam 40 kw, UTRC 15 kw, Grumman 25, Millville 10 kw, Electro 8 kw, Dunlite 2 kw, Enertech 2 kw, and possibly some small VAWTs.

). MARKET DEVELOPMENT PROGRAM (MDP)

The MDP has, as its central elements, been addressing the non-technological issues of wind energy conversion as well as a Public Acceptance Program. Financing alternatives, permitting, wind rights, and other financial, legal, and institutional issues must be addressed as well as environmental and social issues so that difficulties which might delay wind energy's contribution can be identified and minimized. Task forces are already meeting and efforts are being made to eliminate possible barriers, and to develop the needed infrastructure in the state -- people, skills, services -- which will lead to rapid utilization of wind.

CONCLUSION

The HNEI Wind Energy Program seeks to accelerate wind energy's contribution to Hawaii's energy needs. Though the primary application will be electrical, other applications (water pumping, irrigation, thermal, etc.) will be utilized fully, where feasible. Energy storage systems, including a major effort to shift to electric and hybrid vehicles, will increase the level of wind energy utilization in Hawaii. The 80 MW agreement between Windfarms Ltd. and the Hawaiian Electric Company, to be on line in three to four years, one of a number of aggresive programs initated by the private sector in Hawaii, is a most singular event and will give wind energy world wide a major forward thrust. Because of the exceptional wind regime in Hawaii, our dependency on imported oil, and the average cost of electrical energy above 10 cents a kwh in 1981, Hawaii represents the ideal test lab for implementation of large scale wind energy conversion.

This fact is confirmed by the results of the U.S. DOE MOD OA 200 kw WTG at Kahuku on Oahu. The 1,000 hour shakedown period was completed in August 1980, less than two months after its dedication. During this period, the Kahuku MOD OA produced 170,640 kwh--85percent of capacity and appreciably higher than the amount of power generated during the shakedown period at any of the other three MOD OA test sites.

WIND RESOURCE ASSESSMENT IN THE NORTHEAST UNITED STATES

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Wind data summaries for over 375 locations were employed in the Northeast Wind Resource Assessment performed for the U.S. Department of Energy. Approximately 230 of these station summaries were derived from data archived at the National Climatic Center. The remaining summaries were obtained from utility companies, university research organizations, state governments, and the Canadian Atmospheric Environment Service. Upper-air data were employed in making estimates of wind power on mountain tops and ridge crests.

The annual average wind power density in the Northeast is shown in Figure 1. The analyses of mean wind power apply to terrain features that are favorably exposed to the wind, such as mountain summits, ridge crests, hilltops, and uplands. However, terrain features may interact with the wind field to cause wind power at some exposed sites to vary as much as ± 50 to 100 percent from the assessment value. The percentage of land area that is favorably exposed to the wind strongly depends on the land-surface form. The high wind resource areas (class 4 and higher) are dispersed over large areas such as on the mountain summits and ridge crests of several ranges of the Appalachians as well as in the coastal areas along the Atlantic Ocean and the Great Lakes. Class 6 wind power is found in the highest elevations of Maine's Longfellow Mountains, New Hampshire's White Mountains and New York's Adirondack Mountains. The higher ridges of the Green Mountains in Vermont and the Catskills in New York have class 5 wind power, while the highest elevations in Pennsylvania have class 4 power. Exposed coastal locations and the offshore waters have at least class 5 wind power, with class 6 occurring along the New Jersey and Massachusetts coasts and class 7 evident over the offshore waters near Maine. Class 4 occurs along the shorelines of Lakes Erie and Ontario, while class 6 exists over the center of each of the lakes.

Table 1 summarizes the results of the computation of the areal distribution of wind power for the region. Class 3 or higher is shown on 46 percent of the map land area. However, these power classes are actually representative of ridge crests and mountain summits (shaded area on the map). As a result of the relatively low amount of well-exposed land area in these mountainous regions, the estimate of the actual fraction of land area that experiences class 3 and higher wind power is only 10 percent. In contrast to the effect of terrain on the area with high power classes, the land area estimated to have low, class 1 power (about 72 percent for the region) is much larger than the map suggests (26 percent).

Throughout the Northeast winter is the season of maximum wind power. Wind power classes reach 6 and 7 in the exposed mountains and ridges in Maine, New Hampshire, Vermont, New York, and Pennsylvania, as well as in coastal areas. Summer is the season with the lowest wind power. The average wind power on the higher exposed ridge crests and mountain tops is estimated to be the same power class for both spring and autumn. However, the valleys and basins generally have lower wind power in autumn than in spring because of greater atmospheric stability in autumn.

Areas which have a high degree of certainty associated with the wind power estimates include the relatively flat areas of northeastern, central, and southern Maine,

eastern Massachusetts, northwestern and southeastern Pennsylvania, central New Jersey, and the Hudson River, Mohawk River and St. Lawrence River valleys of New York. The high degree of certainty in these areas results from low complexity of the terrain, low spatial variability of the resource and the availability of the existing data. The wind resource estimates in coastal areas are less certain, as the winds have a high spatial variability. The estimates are also less certain in mountainous areas where upper-air data were used to approximate the power on mountain and ridge tops.

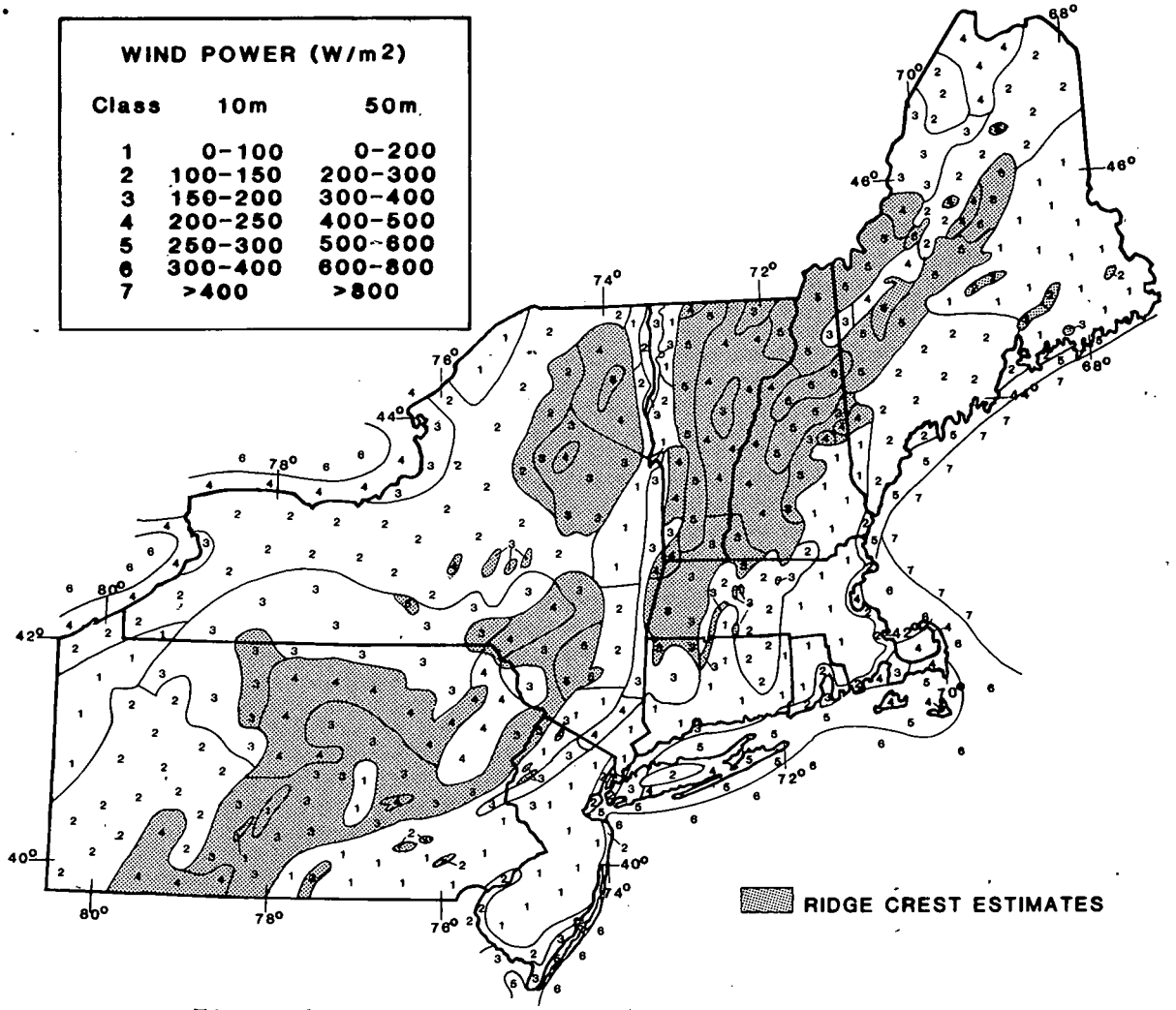


Figure 1. Northeast Annual Average Wind Power

Table 1. Areal Distribution of Wind Power in the Northeast

Power Class	Percentage Land Area Equal or Exceeding Power Class						
	Northeast	CT, MA, RI	Maine	NH, VT	New Jersey	New York	Pennsylvania
1	100.	100.	100.	100.	100.	100.	100.
2	28.	19.	31.	11.	21.	47.	17.
3	10.	7.4	6.2	7.4	13.	13.	12.
4	3.6	2.6	3.5	5.8	0.44	3.8	3.3
5	0.76	0.88	1.6	2.5	0.00	0.33	0.00
6	0.11	0.02	0.43	0.12	0.00	0.02	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TECHNICAL AND ECONOMIC FEASIBILITY OF WIND TURBINES IN THE NORTHEAST UNITED STATES

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INTRODUCTION

The Department of Energy and the Solar Energy Research Institute are sponsoring a series of six regional assessment studies (covering the entire country) aimed at identifying the potential for solar electric technologies and identifying applications that represent the best potential markets with opportunities for early commercialization. One of the solar electric technologies showing the earliest promise is wind. This paper is based on the work done for the Northeast Regional Assessment Study, and it focusses on the results obtained for a variety of applications of wind machines in that region. Machines studied included units ranging in capacity from 3.2 kW to 2500 kW, and applications included utility central station as well as a variety of residential, commercial, and industrial distributed installations.

METHODS OF ANALYSIS

For both utility and distributed applications, the basic approach was to determine what it costs (without wind machines) to produce or purchase the electrical energy required for one year. Then wind machines were added to the system and a year's operation was simulated by a computer model that utilized hourly wind data. The difference in production cost (for the utility) or in the annual electric bill (for distributed users) after adding the wind machines is an annual savings that can be used to derive a value for the wind machine. Through application of an appropriate present-value analysis, a breakeven value can be determined which is the amount that could be paid for the machine such that there would be neither loss nor gain over the machine's life. The breakeven value can, in turn, be compared to projections of estimated machine costs in the future to estimate when the machines may begin to be economically viable.

Wind Energy Resources

The Northeast region (which comprised the New England states plus New York and New Jersey as defined for this study) contains many areas where the winds are good. They occur along the coastal areas of both the Great Lakes and the ocean and in the mountains. Different wind energy resource regimes are shown on the map, Figure 1.

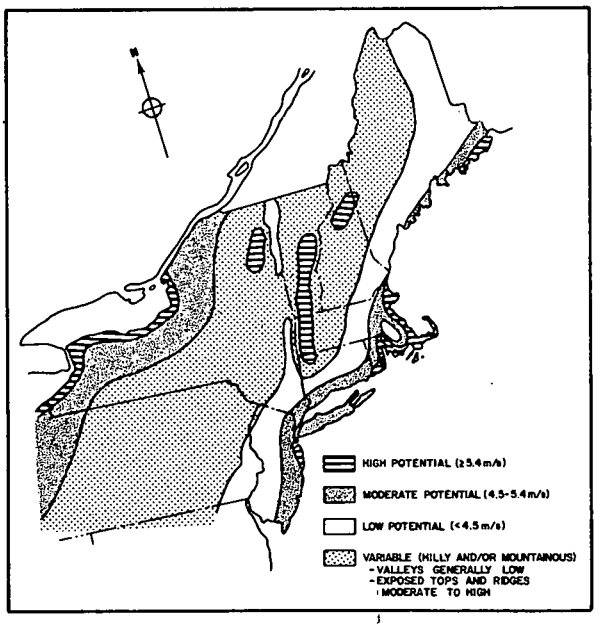
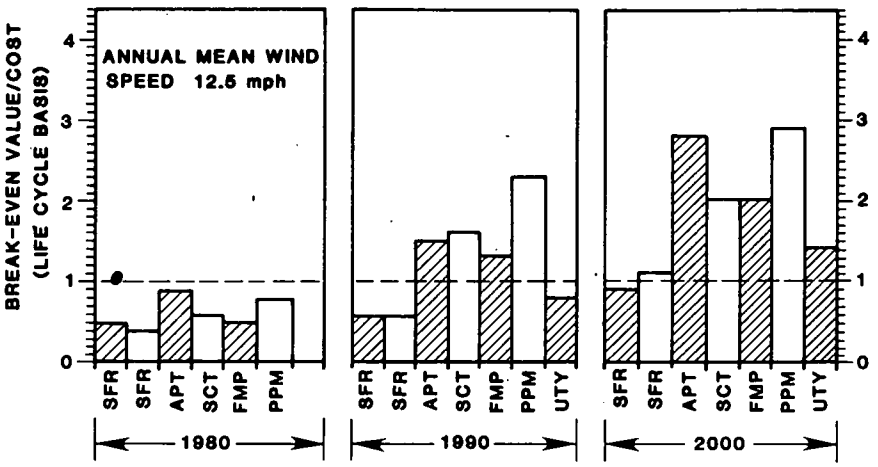


Figure 1. Generalized Wind Resource Regimes

One year of hourly wind data was used in the performance simulations of the wind machines. The data used were taken at Falmouth, Massachusetts, and were obtained from the National Climatic Center.

RESULTS

The results of the investigations of seven different applications of wind machines are summarized in Figure 2 in terms of value-to-cost ratios for three different years of analysis. These results are based on analyses completed in 1978. They are conservative estimates for 1980 for two reasons: (1) fossil fuel costs have escalated at higher rates than were assumed, and (2) both federal and state tax credits have been passed that materially improve the apparent value-to-cost ratios. Taking both these into account, it is estimated that all applications would show current value-to-cost ratios exceeding one.



SFR: Single-Family Residence (3.2 kW and 8 kW); APT: Apartment
SCT: Shopping Center; FMP: Fluid Milk Plant; PPM: Pulp and Paper Mill; UTY: Central Station Utility

Figure 2. Value-to-Cost Results for Seven Applications of Wind Turbines (1978)

WIND RESOURCE ASSESSMENT IN THE NORTH CENTRAL UNITED STATES

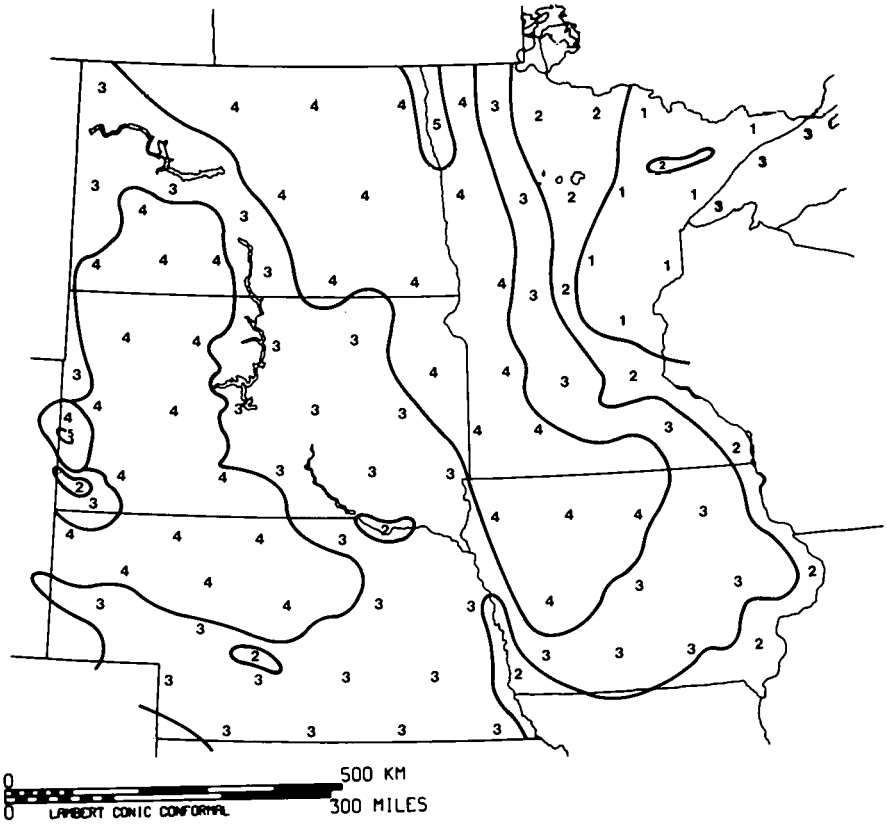
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An extensive search was conducted for wind data in the North Central United States, a region that includes the states of Iowa, Minnesota, Nebraska, North Dakota, and South Dakota. These data included all data on file at the National Climatic Center (NCC), as well as data from universities, air pollution control agencies, and private organizations.

These data were analyzed for long-term seasonal and annual wind power characteristics. Figure 1 presents the results of this analysis in terms of annual average windpower availability at well-exposed sites in the region. Highest wind power in the region (Class 4 or greater, P >199 w/m^2 at 10 m above ground) is found in two large sub-regions: the High Plains of the western Dakotas and northwest Nebraska, and the Flat Plains of eastern North Dakota, western Minnesota, and northern Iowa. Greatest wind power throughout the region occurs during periods of strong northwesterly synoptic winds. However, in the southern portions of the region strong southerly synoptic winds contribute significantly to the annual wind power.

FIGURE 1: Average Annual Wind Power

Class	Wind Power Density Watts/m^2
	0
1	
	100
2	
	150
3	
	200
4	
	250
5	
	300
6	
	400
7	
	1,000



In northern North Dakota and on ridge crests of the Black Hills maximum wind power occurs during the winter. Throughout the rest of the region maximum wind power occurs in the spring. Summer is the season of minimum wind power.

Wind power classes in Figure 1 represent well-exposed sites in the region. In the High Plains sub-region, more sheltered sites at lower elevations in the valleys and basins will have less wind power. In areas of highest relief such as the Black Hills and the Nebraska Sand Hills, wind power will be significantly lower in sheltered river valleys. In the low relief Flat Plains sub-region, most locations will have the wind power class shown. Table 1 presents the actual land area distribution by wind power class in the region. Figures in this table were computed using estimates of land surface form characteristics on a one-third degree longitude by one-quarter degree latitude grid superimposed over the region.

TABLE 1 Areal Distribution (km^2) Equal or Exceeding Power Class

Power Class	Land Area (km^2) Equal or Exceeding Power Class					
	North Central	Iowa	Minnesota	Nebraska	N. Dakota	S. Dakota
1	934,241	145,825	209,657	200,384	181,216	197,159
2	786,918	134,546	148,509	170,711	163,196	169,955
3	655,042	101,559	108,166	138,153	156,802	150,363
4	315,681	35,484	59,048	40,393	114,653	66,104
5	8,170	0	3,923	0	3,748	446
6	0	0	0	0	0	0
7	0	0	0	0	0	0

Power Class	Percentage Land Area Equal or Exceeding Power Class					
	North Central	Iowa	Minnesota	Nebraska	N. Dakota	S. Dakota
1	100.00	100.00	100.00	100.00	100.00	100.00
2	84.23	92.27	70.83	85.19	90.06	86.20
3	70.11	69.64	51.59	68.94	86.53	76.26
4	33.79	24.33	28.16	20.16	63.27	33.53
5	0.87	0.00	1.87	0.00	2.07	0.23
6	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00

WIND ENERGY RESOURCE ASSESSMENT FOR THE GREAT LAKES REGION

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The current measurement programs at Ludington, Michigan and Sandusky, Ohio are designed to assess the wind energy resource at favored sites near the Great Lakes. Are these sites typical of shoreline wind energy resources elsewhere in this region? How is wind energy potential distributed more generally throughout the 5-state region: Wisconsin, Michigan, Ohio, Illinois and Indiana? These questions are answered in our paper, which describes salient results from a wind energy resource assessment of the region.

We first discuss wind energy potential, emphasizing where it appears highest. Seasonal variations in the wind energy resource, and its annual average, are shown in a set of maps for each state and for the entire region. These maps demarcate areas of different (discrete) "wind power class" - that is, areas that differ in estimated wind power available at favorably exposed sites. The observed inter-seasonal differences are largely explained by the seasonal progression of mesoscale and synoptic wind fields. Highlighting the areas of highest apparent wind power, we illustrate how local factors - meteorology, topography, surface characteristics and site exposure - can dominate the wind energy potential of a site. For example, some lakeshore locations show especially high potential.

Estimating the wind power potential is only the first step in wind energy resource assessment. Topographic charts, land form maps and other information are then used to make "areal distribution" estimates of wind power class for each map grid square. These are aggregated by wind power class to make refined estimates of the fractional area in each state, and in the entire region, corresponding to each wind power class. "Certainty ratings" assigned to these estimates are illustrated and explained.

Finally, we try to show how this regional study relates to the broader question of national wind energy resources by comparing results for the Great Lakes Region with those available now from the other DOE-sponsored regional assessments.

WIND RESOURCE ASSESSMENT IN THE SOUTHEAST UNITED STATES

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Wind data from 185 stations and mountaintop wind estimates at 69 locations were used to produce a wind energy resource atlas for the southeast United States including Alabama, Florida, Georgia, Mississippi and South Carolina. Wind data sources included the National Climatic Center, nuclear and fossil fuel utility plants, the National Fire Weather Data Library, and universities.

Wind power maps were prepared for the region and states on an annual basis and for the states on a seasonal basis. Results indicate that the wind power density for the Southeast region is low; more than 98 percent of the exposed regional land area has annual wind power densities less than 100 Wm^{-2} (see Figure 1). The areas of maximum wind power density are located on the exposed ridge and mountaintops in the southern Appalachians (particularly extreme northwest South Carolina) and along the Atlantic shoreline from South Carolina to southern Florida; wind power densities at 10 m average 200-250 Wm^{-2} and 150-200 Wm^{-2} for these areas, respectively. Shoreline wind power densities along the Gulf coast average 100-150 Wm^{-2} at 10 m. The offshore coastal areas in the Atlantic Ocean and Gulf of Mexico have the most wind power potential (250-300 Wm^{-2}) in the Gulf and 300-400 Wm^{-2} off the coast of Georgia and South Carolina, but current development of offshore areas is not economically feasible.

Wind power densities are universally low (less than 100 Wm^{-2}) over the entire Southeast region, including exposed ridge crests and mountaintops, during the summer. Offshore, summer wind power densities range from 100-150 Wm^{-2}. Wind power densities are highest in winter (250-300 Wm^{-2}) on the exposed mountaintops in northwest South Carolina and highest in spring (200-250 Wm^{-2}) along the southeast Florida shoreline. Higher wind power cannot be expected with consistency along the southeast Florida shoreline in spring because of large diurnal variations in wind speed. However, economically commercial wind power may be effectively stored in this shore zone from noon to 6 PM on most days in spring. More consistent wind power can be expected in winter and spring on the exposed ridge crest and mountaintops in northern Georgia and northwest South Carolina.

An evaluation of the land-surface form for each one-fourth degree latitude by one-third degree longitude in the Southeast indicates that a vast majority of the terrain is well exposed for wind turbine siting. Certainty ratings were developed for the same grid spacing based on quality of data, complexity of terrain, and geographic variability of the resource; intermediate to high certainty ratings dominate the Southeast region. Even though much of the topography in the Southeast is well exposed and despite a reasonably high degree of confidence (certainty) in the wind power estimations, the relatively low wind speeds make the wind energy resource potential in this region quite limited.

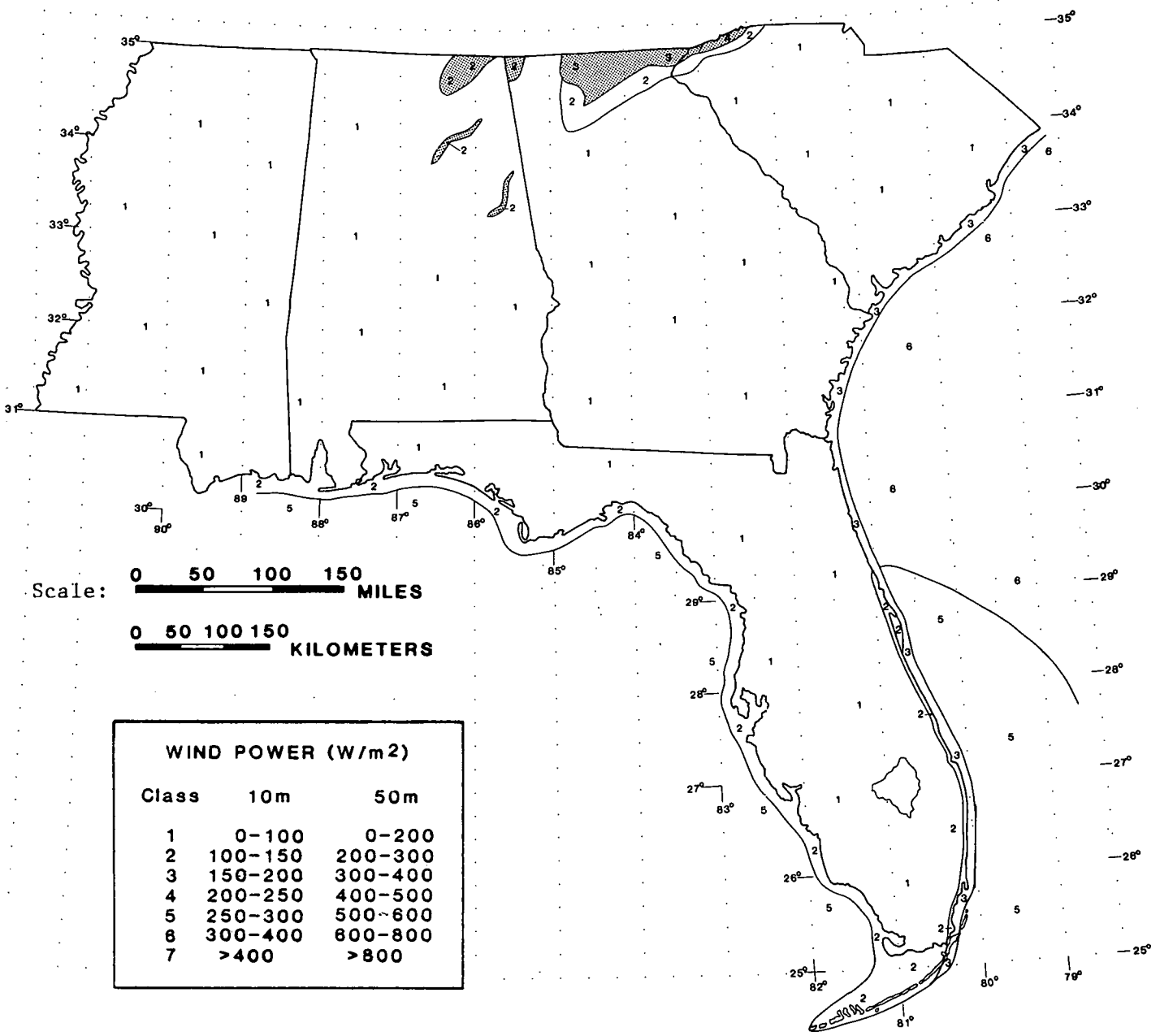


Figure 1. Southeast Annual Average Wind Power Classifications

WIND RESOURCE ASSESSMENT IN THE SOUTHWEST UNITED STATES
The Southern Rocky Mountain Region

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A comprehensive survey was conducted for wind data in the Southern Rocky Mountain Region composed of the states: Arizona, Colorado, New Mexico and Utah. Wind data located for use in the wind resource assessment was supplied by the National Climatic Center in Ashville, North Carolina, by State Government agencies, Federal Government research groups, and the private sector. Cooperation of private companies in the utility, mining and manufacturing industries contributed significantly to the analysis.

The data was analyzed for long-term seasonal and annual estimated wind power characteristics at well exposed sites throughout the region. The interaction between the complex terrain in the Southern Rockies Region and prevailing winds provided large spacial variability of the wind power resource for a significant portion of the region. The annual estimated wind power resource for the region was stratified by the classification scheme presented in Table 1. The highest annual estimated wind power (Class 5 or greater, P $\geq$250 w/m^2 at 10 m above ground) in the region is located on the exposed ridge crests and mountain summits of northern Colorado and southern New Mexico. The mountain top estimates were based on existing mountain top wind data and the use of upper air climatologies for computation of free air velocity at mountain top elevations. The other Class 5 region is located in extreme southeast Colorado and northeast New Mexico. Annual estimated wind power was generally Class 3 or greater for the Eastern Plains Regions of Colorado and New Mexico. In Arizona the annual estimated wind power was generally Class 2 or less except for some mountain summit locations. In Utah, annual estimates for wind power were generally Class 1 in lowland regions throughout the state with the exception of a Class 3 wind corridor in the Sevier Desert of southwestern Utah between Milford and Delta, Utah. The Colorado River Drainage of eastern Utah, western Colorado and northwest New Mexico had an annual estimated wind power of Class 1.

On the mountain summits and exposed ridge crests the maximum wind power occurs during the winter. Throughout the rest of the region maximum wind power occurs in the spring. Summer and fall are the periods of minimum wind power.

The wind power classes represent estimated wind power potential at well exposed sites in the region. On the eastern plains and central basins, more sheltered sites in valleys will have less wind power. In areas of highest relief, wind power will be significantly lower in sheltered areas. Table 2 presents actual land area distribution by wind power class in the region. Figures in this table were computed using estimates of land surface form characteristics on a one-third degree longitude by one-quarter degree latitude grid superimposed over the region.

TABLE 1: Estimated Wind Power Classification Scheme
Classes of Wind Power Density at 10m (33 ft)

Wind Power Class	Wind Power Density Watts/m^2	Speed m/s (mph)*
	0	0
1	100	4.4 (9.8)
2	150	5.1 (11.5)
3	200	5.6 (12.5)
4	250	6.0 (13.4)
5	300	6.4 (14.3)
6	400	7.0 (15.7)
7	1,000	9.4 (12.1)

* Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density for standard sealevel conditions.

TABLE 2: Areal Distribution (km^2) Equal or Exceeding Power Class

Power Class	Land Area (km^2) Equal or Exceeding Power Class				
	Southern Rockies	Colorado	New Mexico	Arizona	Utah
1	752,392.	152,538.	162,376.	265,984.	171,494.
2	139,517.	32,759.	73,145.	19,790.	13,824.
3	135,162.	57,390.	55,242.	7,906.	14,624.
4	37,968.	20,851.	10,160.	0.	6,957.
5	21,183.	3,122.	12,244.	0.	5,756.
6	1,207.	203.	576.	0.	428.
7	1,268.	79.	622.	0.	567.

Power Class	Percentage Land Area Equal or Exceeding Power Class				
	Southern Rockies	Colorado	New Mexico	Arizona	Utah
1	100.00	100.00	100.00	100.00	100.00
2	30.91	42.86	48.35	9.45	19.73
3	18.09	30.59	25.08	2.73	13.26
4	5.67	9.09	7.51	0.00	6.42
5	2.17	1.27	4.28	0.00	3.16
6	0.23	0.11	0.38	0.00	0.47
7	0.12	0.03	0.20	0.00	0.27

THE TECHNICAL AND ECONOMIC FEASIBILITY OF WIND TURBINES IN THE SOUTHWEST AND SOUTHEAST UNITED STATES

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This paper is abstracted from the findings of two separate DOE funded evaluations of various solar electric generation options, including wind. The first study, performed between October 1976 and October 1978, covered the Southwest Region of the United States and is reported on in full in the four-volume report No. DOE/CS/8720 dated August 1979. The second study, conducted between October 1977 and January 1979, covered the Southeast Region of the United States and has only recently been published in final form. Both studies were undertaken by Stone & Webster and a number of utilities in each region to assist the DOE in establishing plans to accelerate the commercialization and market penetration of solar electric generation in each of the regions. The Southwest regional study differed from the other regional studies reported on at this conference in that it did not evaluate the potential for dispersed applications of solar electric technologies. Since the data and evaluations reported upon in the original studies are somewhat dated, a recalculation has been made to reflect the effect of changes in fuel costs, costs of construction of wind plants, and a revised assumption of operation and maintenance expenses.

Wind Resource

In the Southwest and Southeast studies, accurate data on wind resources were most difficult to obtain. Most wind data have been historically measured at airports which are not representative of the most favorable wind resources in a given area. Historical wind data measurements were made close to ground level and empirical calculations are required to approximate the wind resource at an elevation representative of the horizontal axis of a wind machine. Wind was modeled on three utility systems in the Southwest Study: the San Gorgonio Pass (about 8 miles northwest of Palm Springs, California) on the Southern California Edison System; El Paso, Texas, for El Paso Electric Company; and Denver, Colorado, for the Public Service Company of Colorado. The Southeast is characterized as having a poor wind resource, and while wind was scheduled to be modeled on the TVA system, no suitable wind data could be found to justify the modeling effort.

Conceptual Design and Cost Estimates of a Wind Power Central Station

Conceptual design of a wind plant for the Southwest Project was based on using seven 1.5 MWe wind machines with a cut-in speed of 11 mph, a cut-out speed of 50 mph, and a rated speed of 30 mph. These machines had a rotor diameter of 180 ft and operated at 40 rpm. They are not representative of any of the wind machines now in use but were based on design data for a machine planned in 1977. Detailed estimates were made for the wind plant using typical utility estimating practices. A variable, representing the high and low expectations of the wind turbine and accessory electrical equipment costs, resulted in an installed cost of the wind plant, in 1977 dollars, of between $856 per kW (low range) to $1,153 (high range). Using construction cost indices, this has been updated to $1,187/ $1,598 in 1980

dollars. In both instances, the lower cost figure was for the "Nth" plant. These estimates did not contain a contingency allowance. A subsequent design for the Southeast Study used five 2 MWe wind machines with a 26 mph rated wind speed and an 11 mph cut-in speed. The five-turbine wind plant was estimated to cost from $800 to $1,100 per kW in 1978 dollars, the range depending on the maturity of the design. This later estimate showed a cost reduction of approximately 10 percent for the larger machines, indicating little cost sensitivity to machine selection.

Evaluation Methodology

Complex computer programs were developed to evaluate the integration of wind electric generation on the utility systems modeled. The methodology is explained in detail in Volume III of the Southwest Project report. The essence of the modeling effort was to determine the conventional generation expansion plans of each utility modeled through the year 2000. This allowed a base case computer run to determine the costs of dispatching electric power from conventional generation to the utility system through the year 2000 using utility provided economic evaluation data, including fuel costs, fuel mix, and fuel escalation rates. It also provided a base determination of the loss-of-load probability using conventional forms of generation. With a market penetration of 5 or 10 percent installed solar capacity, the computer determined the amount of conventional generation that could be removed from the system while maintaining the same loss-of-load probability and dispatching of electric power needs on the utility system (as in the base case) through the year 2000. To give credit to the solar investment, it also carried the fuel savings of the installed solar equipment through the year 2020.

Results

The system integration studies established the investment that utilities could justify to incorporate wind energy electric power generation plants on their systems based on a "break-even" investment cost. This was the capital investment that could be justified to equal the present worth value of the fuel saved and the present worth differences in operation and maintenance expenses over the life of the plant, based on certain assumptions of escalation and fixed charges. The results were as follows, based on updating the evaluations made in the study to 1980 fuel values, construction costs, and a reassessment of expected O&M costs of wind machines that reduced their annual maintenance costs from $66/kWe to $30/kWe. No storage was included in any of the evaluated cases. All values are given in 1985 dollars.

Utility	El Paso Electric	So. Cal. Edison	Pub. Serv. of Colorado
Credit for Capacity Displaced, $/kWe	$330	$304	$507
Fuel Credits, $/kWe	265	870	537
O&M Penalty, $/kWe	(215)	(215)	(215)
Total Value	$380	$961	$829
Estimated Plant Costs, kW	----------$1,588/$2,138----------		
Negative Value to Utility:	$1,208/$1,758	$627/$1,177	$759/$1,309

This negative value represents the added fuel savings, capacity credits, or the funds needed from grants or other financial incentives that are required to make the installation of wind turbines economically competitive with conventional generating plants.

Based on the results of the Southwest Project and the Southeast Study, we are convinced that the next thrust required to further acceptance and use of wind as a renewable energy source by the utility industry is to develop a precise understanding of where the nation's wind resources are located and site-specific quantification of these resources.

Dup

WIND RESOURCE ASSESSMENT IN THE NORTHWEST UNITED STATES

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The Northwest United States includes three of the wind resource assessment regions delineated by the Pacific Northwest Laboratory (PNL): the Northwest region (Idaho, Montana, Oregon, Washington, and Wyoming), the Alaska region, and the Hawaii region (Hawaii and the Trust Territories of the Pacific). Detailed wind energy resource assessment atlases have been prepared for each of these regions (Elliott and Barchet; 1980, Wise et al. 1980, Shcroeder and Hori 1980); only the highlights are presented here.

All the assessments applied the techniques described by Elliott (1980) to evaluate the wind resource. Maps of the distribution of wind power density at well exposed sites are presented in each atlas for annual and seasonal periods. Areas of high wind energy potential (wind power class 4 or higher, 200-250 W/m^2 or 5.6 to 6.0 m/s at 10 m) can readily be identified on these maps.

In the Northwest region the areas of highest wind power include the Oregon and Washington coasts, the Columbia River gorge, the area in the vicinity of Ellensburg in central Washington, the valleys near Whitehall and Livingston, Montana, the plains of northwestern Montana and south central Wyoming and exposed ridge crests and mountain summits throughout the mountainous areas of all the states.

Winter is the season of maximum wind power for most of the mountainous regions, for the northwestern Montana plains and for the plains of south central Wyoming. Other plains or low land areas generally show a spring wind power maximum. The eastern end of the Columbia River gorge and the area near Ellensburg, Washington, have a summer wind power maximum.

In Alaska, high wind power is found mainly in the islands and adjacent coastal areas of the Beaufort, Chukchi and Bering Seas, over the Alaska Peninsula and Aleutian Islands, in the lower Cook Inlet, along exposed portions of the Gulf of Alaska coast, and on the ridge crests and mountain summits of the western portion of the Alaska Range, southeast Alaska, and the eastern end of the Brooks Range.

Winter is the season of maximum wind power at most island, coastal and mountain locations. However, along the western Beaufort Sea and the Chukchi Sea coasts, autumn shows the highest seasonal wind power. Many valleys in the interior show a spring wind power maximum except near mountain passes where a winter maximum predominates.

In Hawaii, the interaction between the prevailing trade winds and island topography prescribes the distribution of wind energy. On all major islands (Kauai, Oahu, Molokai and Hawaii) the trades accelerate over the coastal regions

(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

along the northeast and southeast sides of the islands. Mountain crests and summits within the tradewinds show a high wind resource whereas the highest summits often project above the influence of the trades. Channeling of the trades between mountain masses or through island channels intensifies the wind resource in some areas on Maui, Molokai, and Hawaii. Summer is the season of highest wind power in concert with the most intense trade winds in most locations.

The analyses in the regional wind energy resource atlases pertain to locations well exposed to the wind. They do not apply to sheltered areas or areas of high local surface roughness. An estimate of the extent to which sheltering by local topography reduces the land area experiencing a given wind power was part of each regional assessment. Table 1 summarizes the estimated land area by power class for the three regions. Much of the contribution to Class 4 and higher wind power in the Northwest region is from the plains of northwestern Montana and south central Wyoming. In Alaska the main contribution is associated with exposed coastal plains and islands and with the large area of mountainous terrain. In Hawaii, the exposed coastal margins on the northeast and southeast sides of the major islands contribute most to the land area estimated to experience an annual average wind power exceeding Class 4.

TABLE 1. Estimated Land Area (km^2) by Power Class

Power Class	Northwest	Alaska	Hawaii
1	880,000	1,200,000	16,000
2	120,000	88,000	3,800
3	180,000	60,000	2,100
4	89,000	25,000	1,400
5	25,000	31,000	910
6	5,800	34,000	610
7	200	26,000	60

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2. Wise, J. L., T. W. Wentink, Jr., R. Becker and A. Comiskey, 1980: Wind Energy Resource Atlas: Vol. 10 - Alaska. PNL-3195 WERA-10. Pacific Northwest Laboratory, Richland, Washington.

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TECHNICAL AND ECONOMIC FEASIBILITY OF WIND TURBINES IN THE NORTHWEST UNITED STATES

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INTRODUCTION

The Department of Energy and the Solar Energy Research Institute are sponsoring a series of six regional assessment studies (covering the entire country) aimed at identifying the potential for solar electric technologies and identifying applications that represent the best potential markets with opportunities for early commercialization. One of the solar electric technologies showing the earliest promise is wind. This paper is based on the work done for the Northwest Regional Assessment Study, and it focusses on the results obtained for a variety of applications of wind machines in that region. Machines studied included units ranging in capacity from 1.5 kW to 2500 kW, and applications included utility central station as well as a variety of residential, commercial, and industrial distributed installations.

For purposes of the study, the Northwest region was defined to include 10 states, which were further subdivided into four sectors: Sector I, the Dakotas and Nebraska; Sector II, the Pacific Northwest states plus Montana and Wyoming; Sector III, Hawaii; and Sector IV, Alaska.

METHODS OF ANALYSIS

For both utility and distributed applications, the basic approach was to determine what it costs (without wind machines) to produce or purchase the electrical energy required for one year. Then wind machines were added to the system and a year's operation was simulated by a computer model that utilized hourly wind data. The difference in production cost (for the utility) or in the annual electric bill (for distributed users) after adding the wind machines is an annual savings that can be used to derive a value for the wind machine. Through application of an appropriate present-value analysis, a breakeven value can be determined which is the amount that could be paid for the machine such that there would be neither loss nor gain over the machine's life. The breakeven value can, in turn, be compared to projections of estimated machine costs in the future to estimate when the machines may begin to be economically viable.

WIND ENERGY RESOURCES

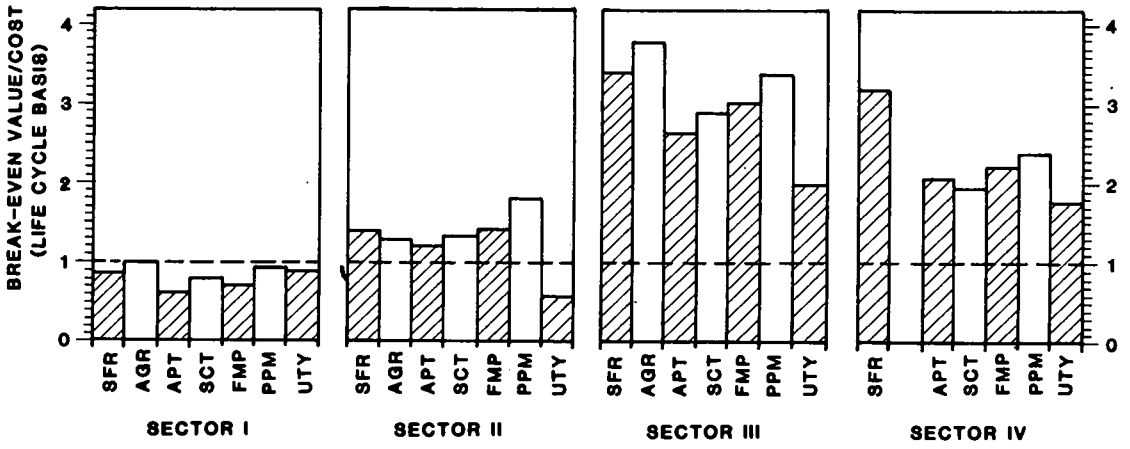
The available wind energy in the study region is as diverse as the region itself. Not only is there great variation in the annual mean wind speed, but seasonal and diurnal patterns also differ from one sector to the other. Accordingly, hourly wind data from a variety of sources were employed. Table 1 gives examples of some of the wind data sets that were utilized.

Table 1. Representative Wind Data Sets

Sector	Representative Resource Station	Period of Record	Average Annual Wind Speed (mph)	Average Annual Wind Power Density (w/m^2)
I	Goodland, KS	1962	12.6	210
II	Columbia Gorge	1976-78	18.1	660
III	Upper Kahuku, HI	1976-79	17.1	555
IV	Middleton Is., AK	1955	14.2	330

RESULTS

Figure 1 compares the breakeven value-to-cost ratios determined for the year 1990 in each of the four study sectors for seven different applications. For all four sectors, the results displayed are based upon the better wind regimes available in each sector. Differences in value among the sectors are accounted for by differences in wind energy resources and electricity costs from competing sources. The largest values are seen in Sector III (Hawaii) and Sector IV (Alaska). In those sectors, values are sufficient to translate into discounted payback periods of the order of five to ten years.



SFR: Single-Family Residence; AGR: Agriculture; APT: Apartment
SCT: Shopping Center; FMP: Fluid Milk Plant; PPM: Pulp and Paper Mill; UTY: Central Station Utility

Figure 1. Year 1990 Value-to-Cost for Seven Wind Turbine Applications

WIND RESOURCE ASSESSMENT IN THE EAST CENTRAL UNITED STATES

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A wind energy resource atlas has been prepared for the East Central region States of Delaware, Kentucky, Maryland, North Carolina, Tennessee, and Virginia. This atlas is a product of the Wind Characteristics Program Element of the Federal Wind Energy Program. The methods used to identify, screen, evaluate, and analyze the various types of data, and to produce the wind energy resource maps and graphs have been described in detail (Brode and Stoner, 1980) based on guidance from Battelle-Pacific Northwest Laboratory. Table 1 summarizes the wind data sources screened and retained in the East Central region wind resource assessment study. Wind data coverage for the region is generally adequate except in mountainous areas. In such data-sparse areas, wind-power estimates are associated with a considerable degree of uncertainty.

TABLE 1 Stations with Wind Data in the East Central Region Screened in the Assessment

Source and Type	Screened	Retained
National Climatic Center		
Digitized	86	82
Summarized	140	96
Unsummarized	142	35
National Fire Weather Data Library	29	2
Nuclear & Fossil-Fueled Power Plant	25	4
Other (University Research etc.)	66 66	5 5

The annual average available wind power density in the East Central region is shown in Figure 1 based on wind power density classes defined in Table 2. The analyses of mean wind power apply to terrain features that are favorably exposed to the wind, such as mountain summits, ridge crests, hilltops, and uplands. However, nearby terrain features may interact with the windfield to cause the wind power at some exposed sites to vary as much as ±50 to 100% from the assessment value. Table 3 summarizes the the results of the computation of the areal distributions of of wind power for the region. Winter and spring are seasons of maximum wind power throughout the region, as indicated in Figure 2.

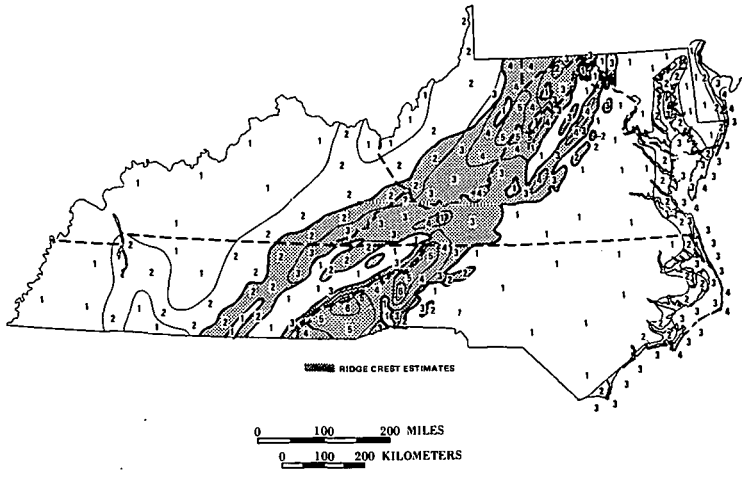


FIGURE 1. Annual Average Wind Power in the East Central Region

The annual average wind power for exposed coastal and offshore areas of Delaware, Maryland, Virginia, and North Carolina is estimated to be at least class 3, with class 4 wind power likely in the better exposed areas. There is a steep gradient in the estimated wind power within several kilometers of the coastline. The prevailing wind direction has a significant along-shore component for the Delmarva Peninsula and for the North Carolina coast south of Cape Hatteras.

TABLE 2 Classes of Wind Power Density at 10 m and 50 m[a]

Wind Power Class	10 m (33 ft) Wind Power Density, watts/m²	10 m (33 ft) Speed,[b] m/s (mph)	50 m (164 ft) Wind Power Density, watts/m²	50 m (164 ft) Speed[b] m/s (mph)
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	500	9.4 (21.1)	2000	11.9 (26.6)

[a] Vertical extrapolation of wind speed based on the 1/7 power law.

[b] Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/500 ft (3%/1000 m) of elevation.

TABLE 3 Areal Distribution of Wind Power Classes in the East Central Region

Power Class	Land Area (km^2) Equal to or Exceeding Power Class: East Central	Delaware/Maryland	Kentucky	North Carolina	Tennessee	Virginia	West Virginia
1	530,000	30,000	100,000	130,000	110,000	100,000	63,000
2	57,000	8,800	2,400	12,000	17,000	13,000	3,000
3	10,000	1,400	160	1,400	470	4,700	2,000
4	3,300	220	0	930	170	1,000	930
5	760	2	0	410	46	48	250
6	75	0	0	57	18	0	0
7	0	0	0	0	0	0	0

Power Class	Percentage Land Area Equal to or Exceeding Power Class: East Central	Delaware/Maryland	Kentucky	North Carolina	Tennessee	Virginia	West Virginia
1	100.	100.	100.	100.	100.	100.	100.
2	11.	29.	2.4	9.5	16.	12.	6.1
3	1.9	4.5	0.15	1.1	0.43	4.5	3.1
4	0.61	0.72	0.00	0.73	0.15	0.99	1.5
5	0.14	0.01	0.00	0.33	0.04	0.05	0.39
6	0.01	0.00	0.00	0.05	0.02	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00

These areas have the highest wind potential since they are better exposed to the prevailing winds. Winter is the season of maximum power for most of the coastal areas of the region. Coastal wind power also has a very definite variation with latitude, being higher in the north. This is related to the relative increase in in surface pressure gradients with latitude.

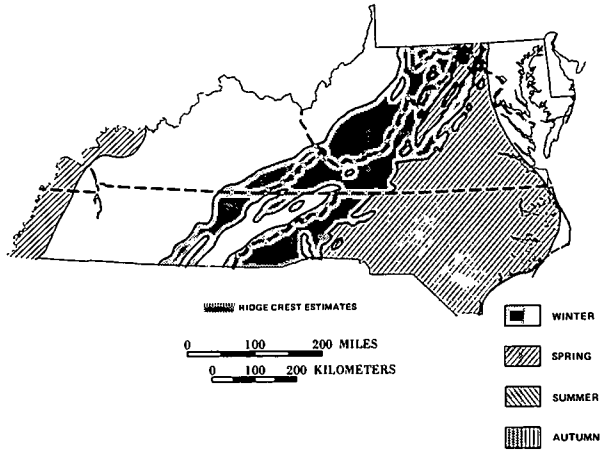


FIGURE 2. Seasonal Maximum Wind Power in the East Central Region

Exposed areas of the eastern shore of the Chesapeake Bay and Cape Henlopen at the mouth of the Delaware Bay are estimated to have class 4 wind power. This is because of the large fetch over open water for the main power-producing winds out of the west through north directions in these areas. The complexity of the Chesapeake Bay shore line, with its many islands and inlets, suggests a high variability of wind power in this area. The highest coastal wind power potential is around the southern tip of the Delmarva Peninsula

Class 4 or higher wind power is estimated for exposed mountain summits and ridge crests in western North Carolina, extreme eastern Tennessee, east central West Virginia, western Maryland (west of Cumberland), and portions of Virginia including the higher elevations of the Blue Ridge Mountain Range in Shenandoah National Park. Average wind speeds may vary considerably from one ridge crest site to another, and are primarily influenced by the height and slope of the ridge, orientation to the prevailing winds, and the proximity and relative height of other mountains and ridges. A majority of the ridges in Virginia, West Virginia, and western Maryland are oriented perpendicular to the prevailing westerly winds, and as a result the higher ridges may experience considerably enhanced wind power from a venturi speed-up effect as forced over the ridges.

Additional information is presented in the regional atlas and final project report (Brode and Stoner, 1980). However, the quantity and quality of wind data and topographic information required to make a highly accurate localized appraisal of the wind resource goes far beyond the scope of this regional resource assessment.

Brode R., and R. Stoner, 1980. Wind Energy Resource Atlas: The East Central Region and Regional Wind Energy Resource Assessment - East Central Region: Final Report, prepared by NUS Corporation for Battelle-Pacific Northwest Laboratory in behalf of U.S. Department of Energy, PNL-3195.

WIND RESOURCE ASSESSMENT IN THE SOUTH CENTRAL UNITED STATES

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The solar electric resource region for the South Central United States coincides with the South Central Wind Resource Assessment Region defined by Elliott and Barchet (1980). The region includes the states of Arkansas, Kansas, Louisiana, Missouri, Oklahoma and Texas. The region is bounded on the south by the Gulf of Mexico and on the east by the Mississippi River. The land slopes generally upward to the north and west, reaching the Great Plains at an elevation of 1200 meters. The only portions of the area which are mountainous are the western tip of Texas where the Guadalupe Mountains rise to 2500 meters and portions of Arkansas and Missouri where some hills and mountains reach 700 meters.

As pointed out by Elliott (1980), the primary data used for the wind assessment were summaries of National Climatic Center data. For data sparse regions, a few years of unsummarized data were scanned to provide supplemental information. Other data, such as data from nuclear power plant sites, were also obtained. Data for 165 stations were actually used in preparation of the wind assessment.

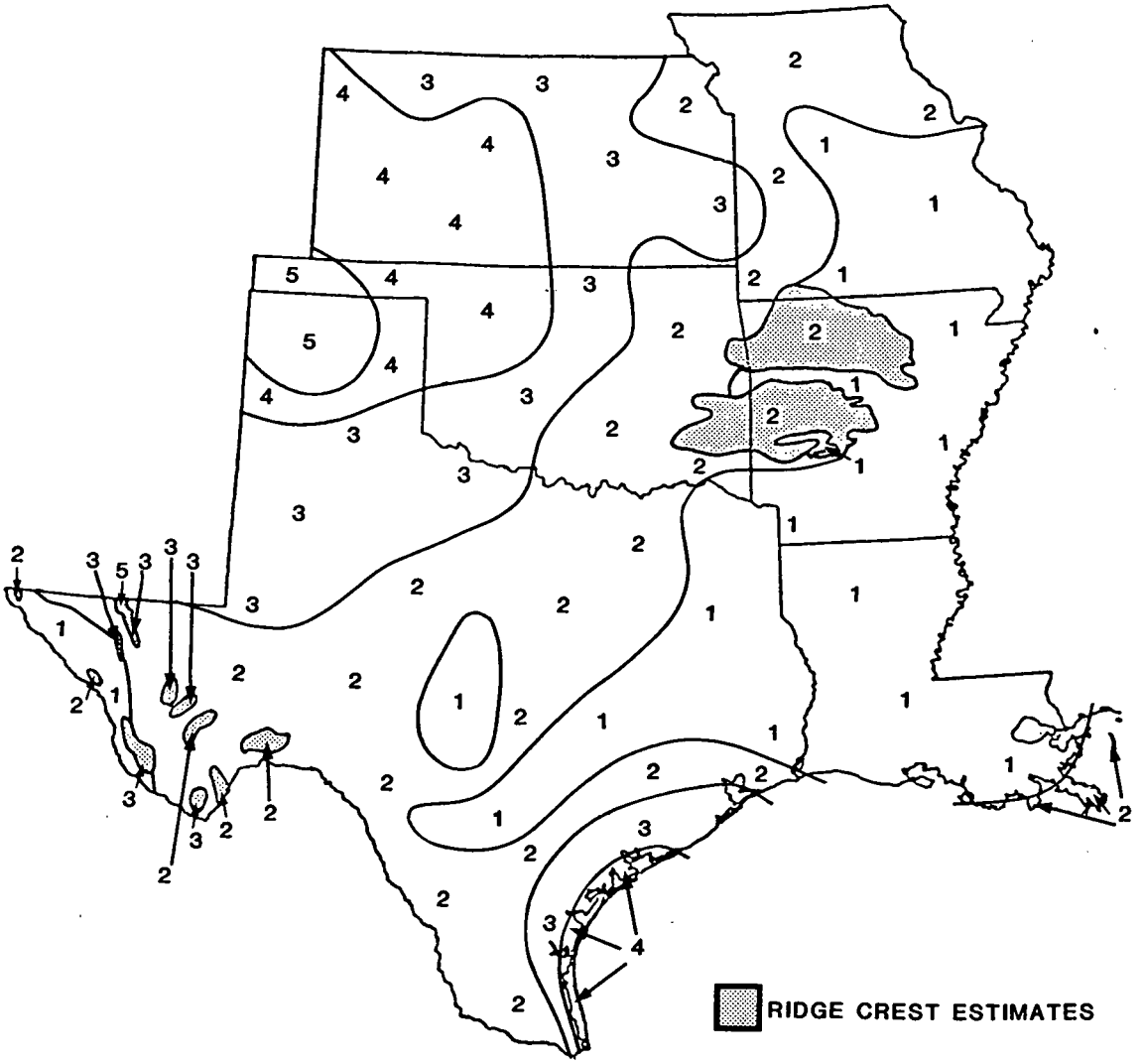
Elliott (1980) has defined classes of wind power density. If we assume that an annual average wind power density of Class 4, in excess of 200 w/m^2 at 10 m or in excess of 400 w/m^2 at 50 m, is an adequate wind energy resource, an area of about 200,000 km^2 of the Great Plains, or 15% of the area of the South Central Region qualifies as adequate (See Figure 1). Actually 40,000 km^2 of western Oklahoma and southwestern Kansas averages Class 5, in excess of 250 w/m^2 at 10 m or 500 w/m^2 at 50 m. The land form here is classified as smooth plains with gentle slopes or irregular plains with moderate relief. From this maximum, the average annual wind power density decreases rather uniformly toward the east and south as the elevation decreases, becoming Class 1, less than 100 w/m^2 at 10 m, and less than 200 w/m^2 at 50 m, along a line through central Texas, western Arkansas and central Missouri, except for some ridge crest estimates in Arkansas and West Texas. From central Texas, the density increases southward again, becoming Class 4 within 50 km of the coast of South Texas. Here the frequency of winds with a southerly component increases from day to night in all seasons. The wind power also averages higher at night than during the day in all seasons.

The wind resource in the winter season is similar to the annual average resource. However, in the spring season, the area covered by Class 4 increases to approximately 400,000 km^2 and the winds of class 6 are observed over some 40,000 km^2. In summer, the Great Plains maximum is Class 3, with a general decrease in wind energy toward the south and east. From summer to autumn there is essentially no change except for the appearance of a small region of Class 4 wind power in the Texas Panhandle.

Elliott, D. L., 1980. National Wind Resource Assessment Methodology. Renewable Energy Conference Proceedings, Honolulu, Hawaii.

Elliott, D. L. and W. R. Barchet, 1980. Wind Energy Resource Atlas: the Northwest Region. PNL-3195, Pacific Northwest Laboratory, Richland, WA 99352.

Figure 1. South Central Region Annual Average Wind Power



IMPACT OF FEDERAL LEGISLATION ON WIND ENERGY SYSTEMS

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In the past few years, the Congress has enacted a wide range of energy legislation with the common goal of reducing the nation's dependence on imported oil and encouraging the development of domestically abundant or renewable energy technologies. The impact of these laws during a period of rising energy cost and maturing Wind Energy Conversion Systems (WECS) technology, combine to provide a significant stimulus to WECS commercialization. Below, we discuss those laws that are only the most prominent and directly WECS-related of the field; there are a wide variety of others (e.g., the Fuel Use Act of 1978, the Energy Security Act of 1980, etc.) that will have subtle, yet still important impacts.

National Energy Conservation Policy Act (NECPA) of 1978 and the Residential Conservation Service (RCS). This law, in only one of its many provisions, created the RCS, under which electric and gas utilities must offer conservation and renewable energy resources audits to their residential customers. For most areas, such audits will include estimates of SWECS cost effectiveness and dissemination of manufacturer and installation information. The regulations issued include SWECS standards and siting restrictions. The IMPACT of this law will be to increase consumer awareness of SWECS and make it easy for purchase decisions to be facilitated (utilities must arrange installation and financing). STATUS: final DOE regulation issued.

Public Utility Regulatory Policies Act (PURPA) of 1978. This law mandates utility power supply to WECS using customers on a non-discriminatory basis, and further requires utilities to purchase excess energy at their "avoided costs" (e.g., equal to the dollars the utility actually saves) or, if deemed appropriate by the state PUC (who sets the actual rates), at a higher rate designed to encourage use of renewables. Such "buy back" rates for oil burning utilities can be quite high (as much as 6¢/kWh), significantly improving SWECS economics. Moreover, by exempting such "Small Power Producers" of 30 MW or less from utility type regulation, they become eligible for the Energy Tax Credits (see below). We believe a whole new industry (of companies such as Windfarms Ltd.) will develop to take advantage of this law. IMPACT: improves the economics of SWECS and creates a class of heavily incentivized risk takers who will demonstrate the viability of LWECS on a rapid schedule. STATUS: final FERC regulations issued.

Crude Oil Windfall Profits Tax Act of 1980. This law provides for a 40% tax credit on the first $10,000 of expenditure for residential SWECS, expiring on December 31, 1985. For businesses, the "business energy investment tax credit" for WECS is 15% (in addition to the normal 10% ITC, for a total of 25%), also expiring in December, 1985. Interestingly, this tax credit is denied to utilities. IMPACT: provides a significant financial stimulus for large and small WECS, makes ventures such as Windfarms Ltd. very attractive, and dictates their fiscal structure as tax advantaged investment vehicles. STATUS: law passed, IRS regulations not issued but companies and individuals can proceed.

Wind Energy Research, Development and Demonstration Act of 1980. The "Mineta Bill" would establish U.S. wind power goals (800 MW by 1988: 700 MW for LWECS, 100 MW for SWECS) and require DOE to carry out a wide range of supportive management and RD&D activity. In addition, it includes a substantial subsidy program (direct cost sharing up to 50%) in the House version and a low interest loan program in the Senate version. These subsidies will probably be distributed in a series of DOE procurements. IMPACT: generally positive and stimulative in the early years of WECS commercialization; one danger is that prospective customers (especially SWECS) will wait for DOE subsidies rather than take advantage of the tax credits or PURPA incentives. STATUS: In House-Senate conference at this writing (July, 1980); passage ultimately expected.

We can expect that the effect of these laws will be to greatly stimulate the demand for WECS. One difficulty will be the relative immaturity of the WECS industry (both large and small systems) in light of this market demand. In their rush to fill market needs and beat the December, 1985 energy tax credit expiration date, manufacturers may produce machines lacking the requisite level of testing and quality control. Unless the industry can police itself (through design, manufacturing, installation and operation standards, for example) to prevent this occurrence, early and highly publicized WECS failures could do much to dampen the enthusiasm for the technology.

NEAR-TERM, HIGH POTENTIAL SWECS MARKET ANALYSIS

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In FY80 the Wind Energy System Division of the DOE tasked SERI with the responsibility to perform a near-term SWECS market analysis that would be of immediate benefit to wind machine manufacturers and distributors. The results presented here today are from the draft final report "Near-Term, High Potential SWECS Market Analysis" for the rural inter-connected residential and agricultural market sectors. The work was performed under a 3 month contract to Arthur D. Little, Inc., as part of the ongoing WECS Market Characterization task of characterizing the WECS market place, determining the market potential for WECS at the county level, and developing an interactive economic and market analysis model to be used by manufacturers, distributors, and local, state and federal government policy makers via terminals located at the State Solar Offices, the Regional Solar Energy Centers (RSEC's), and the SERI.

The objective of this Phase I near-term Market Study was to synthesize the available wind resource data, utility consumption and rate data, demographic data and existing federal and state incentive information and present it in a format that could be easily used by manufacturers and distributors for planning their marketing strategies, promotional campaigns, or future distributorships. The emphasis throughout the study was "to place ourself in the manufacture's shoes and provide and present data that the industry needs now".

The analysis was scoped to include only the residential and agricultural market sectors in the states that required Residential Conservation System (RCS) audits. This was a ground rule to screen out or limit the number of counties that were to be investigated. A major ingredient of the basic approach was to collect the best data currently available on: wind resources (Battelle PNL maps); cost of electricity and electrical use by consumers (Energy Information Administration publications "Typical Electric Bills" and the "The National Electric Rate Book"); electrical use by farms (USDA journal "Agricultural Prices" 10/79); and demographics (Census of Population, Census of Housing, U.S. Census of Agriculture, and USDA publications "Agricultural Statistics", "Agricultural Prices", and "Energy and U.S. Agriculture").

The approach used was to format the data into tables for cross-referencing of wind, utility and demographic information to the state and sub-state region level. County maps were developed that displayed the areas of the county that have average annual wind speeds of less than 10 mph, between 10 and 12 mph, and 12 mph or greater. Lower than average, average, and greater than average county-specific utility rates were then overlayed on the designated wind areas to depict, for example, where the combined high wind and high utility rate areas are situated. All the available data for each county analyzed was synthesized to provide tables of low and high market potential areas that show: the average annual wind speed; the number of sub-market sector units (e.g., high energy consumption residences) as a function of average utility rates within the low (10-12 mph) and high (12 mph and greater) wind areas; and, where available, additional demographic (e.g., age of head of household and average family income) data correlated to the county areas.

Maps and data are available in reports for each of the RCS states, geographical regions, and the USA to assist the manufacturers and distributors in their near-term market planning. The reports also provide state incentive data and case studies that

indicate how all the data can be effectively used to compute the net cost of energy delivered by a wind machine. These SWECS high potential (by-state) market reports are available at SERI and will also be made available at the RSEC's in the near future.

The WECS Market Characterization subtask is a continuation of the effort initiated in FY80 by SERI. The objectives of the FY81 effort are to:

- o Complete an in-depth pilot market analysis study for single geographical region.
- o After review of the Pilot Study methodology and results extend the market analysis capability to include the remaining regions.
- o Coordinate the collection and in-depth analysis of all relevant economic, marketing, WECS performance, environmental, wind regime, demographic, legal, etc., data with the RSEC's and selected subcontractors.
- o Interface with RSEC's and establish requirements for an inter-active WECS performance/economic/market analysis model for use by DOE, SERI, RSEC's and manufacturers to investigate the impacts of new legislation and policies, fuel price escalation, design-to-cost goals, refined wind regime data, etc. on market potential and penetration.

The results presented here today were not available at the time of printing of this abstract.

ESTIMATED GROSS MARKET FOR UTILITY-SCALE WIND TURBINES IN THE UNITED STATES

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In the years since the first oil embargo, the electric utility industry in the United States has been actively looking for alternatives that could displace oil while still meeting the economic and reliability criteria for this industry. Wind power generation is one of the alternatives being seriously considered. This paper presents the results of a market study, funded by the Electric Power Research Institute, that had as its objectives the quantification of the potential gross wind turbine market in the United States and an indication of the regions in which it would most likely emerge. This study simply quantifies the potential market size but does not suggest that the market will actually occur. Market emergence will require that technical, economic, siting, and institutional requirements be met, and that the wind option be more viable than other alternatives.

The approach used was to first identify those states having a wind resource ≥ 300 watts/m^2 (at 50 meters) either within the state or within an area 50 miles wide around the state borders. This latter criterion was used to allow siting in an adjacent state, should this be necessary. The next step was to determine which states had, in 1978, 25% (or more) oil and gas-fired generation. This was also done for the 1990's, based upon utility mix projections. It has been shown in other reports that those utilities with large fractions of oil in their mix, and with good wind resources available to them, display the most promising economics for wind power generation. It was hypothesized utilities using significant amounts of oil and gas will be the most likely early candidates for wind turbine economic viability in the future. The extent to which this happens will be strongly affected by future prices of oil and gas. Subsequently, wind power generation may also become viable for primarily coal-fired or nuclear-fired utilities.

The latest wind resource data was obtained from the literature and from Battelle Pacific Northwest Laboratories. Department of Energy documents were used to obtain current, and future estimated, mixes of generation capacity. It was then assumed for the purposes of this study, that wind turbines would be installed at a level such that their rated power did not exceed 10% of the utilities' installed capacity. The study concluded that the gross size of the market for utility wind turbines could be between 12,000 and 27,000 MW of wind turbine (WT) rated power, provided that:

- WT's become available at costs that make them economically viable
- WT's are demonstrated to be reliable
- Sufficient sites become available for the WT's
- The 10% installation does not cause operational problems on the utility grid

At this writing, none of the above has been demonstrated.

SECTION 5

PHOTOVOLTAICS

PHOTOVOLTAICS

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DOE Advisor: *Paul D. Maycock*
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HISTORY, STRUCTURE AND GOALS OF THE NATIONAL PROGRAM

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Paul D. Maycock
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Program Scope

The Photovoltaics Program is directed toward the development of economically competitive, commercially available, photovoltaic power systems which provide safe and reliable energy for a wide range of applications. In particular distributed grid-connected and total energy residential systems should be able to displace significant amounts of centrally generated electricity first in the Southwest and subsequently, throughout most of the United States. Intermediate size commercial, institutional and industrial on-site systems should provide a similar option. Finally utilities should ultimately be able to augment their generating capacity with larger scale systems.

Program Objectives

The objective of the Photovoltaics Program is to reduce system costs to a competitive level in both distributed and centralized grid-connected applications. Equally important, the Program will also resolve the technical, institutional, legal, environmental and social issues involved in fostering widespread adoption of photovoltaic energy systems. The specific cost goals are:

Basic Goals	Module Prices	Systems Prices	Prime Application
1982	$2.80/peak Watt	$6-13/W	Remote/International
1986	$0.70/peak Watt	$1.60-2.20/W	Residences
1990	$0.15-0.50/peak Watt	$1.10-1.80/W	Utilities

Program Strategy

The Photovoltaic Program Strategy is to achieve major system cost reductions to meet the market requirement for a competitive life-cycle cost of electricity through the aggressive pursuit of Advanced Research and Technology Development. In addition, real-world testing will be pursued to support the accelerated transfer of the technology to the market place.

Key elements of the Program Strategy include:

(1) Substantial reductions in the price of components and sub-systems via:

   (a) Aggressive Advanced Research and Development to bring advanced concepts to the point of Technical Feasibility.

(b) Intensive Technology Development to identify, develop and suitably demonstrate cost-effective designs and production processes for components for which Technical Feasibility has been proven, thereby establishing their Technology Readiness.

(2) Definition, development, design and real-world testing of complete photovoltaic systems by a series of Tests and Applications to demonstrate first that such systems are feasible, by developing operational and effectiveness costs, and second that they are ready for commercialization.

(3) Development of substantial body of experience, confidence, and expertise within the private sector on the part of both users and suppliers of photovoltaic systems.

(4) Careful study and implementation of commercialization strategies that will encourage market penetration and stimulate emplacement of appropriate production capacity as photovoltaic technologies approach Commercial Readiness.

Program Deliverables

Major FY80 deliverables are:

- Issue Balance-of-System Plan.
- Achieve 10% efficiency thin-film cell in laboratory.
- Establish Technology Readiness of $2.80/Wp collectors.
- Decide on purchase mechanisms (e.g. fixed price buy) to establish Commercial Readiness for $6-13/Wp systems and $2.80/Wp collectors.
- Decide on further international remote efforts and complete appropriate.

A budget overview is shown below; figures are in $1000.

	Actual FY 1979	Estimate FY 1980	Estimate FY 1981
Advanced Research and Development	33,087	47,000	50,000
Technology Development	40,546	61,000	60,000
Systems Engineering and Standards	6,492	14,500	15,000
Tests and Applications	23,675	24,500	15,000
Market Development	15,000	10,000	20,000
Totals	$118,500	$157,000	$160,000

SMALL BUSINESS VIEW OF THE STATE OF THE PHOTOVOLTAICS INDUSTRY

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Every industry goes through a series of phases in its life cycle from initial feasibility through full deployment to obsolescence. The Photovoltaics Industry is no exception. In order to understand the state of the industry one must look with the perspective of each phase of the business.

Photovoltaics is today, still in the early feasibility phase and there are three important market segments in this phase: (1) the industrial/commercial segment for remote power applications; (2) the government market for applications similar to the industrial, plus government purchases for those applications oriented toward demonstration of future markets; (3) finally, there is a start in the consumer market. The paper will discuss the state of the industry with regard to each of these market areas.

Much of the current effort in market and industry analysis is directed toward the configuration of the industry in future market phases. There are three market areas in the future phase which are evident today. An expanded industrial/commercial/government market for remote and semi-remote applications. In addition, an expanded consumer market which flows into the residential power supply market, which could provide island power. (Thought by many to be the real long term market for the industry.) There will also be a utility/industrial power source market; however, the size and timing of this market is in question. The paper will discuss the current positioning of the industry to serve these markets in the more mature business phases.

Finally, over-riding and dominating all of these factors is the cost/price structure driven by the technologies and manufacturing capabilities of the industry. The state of this will be discussed.

THE PV INDUSTRY - A LARGE-COMPANY PERSPECTIVE

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Today's PV industry is made-up of a wide variety of entities. While some are backyard and garage operations; others are giant, multi-national corporations. To some of these, PV sales are bread and butter. To others, PV sales are trivial and of little real-time consequence. Almost 400 organizations, world-wide, make up this industry - quite an increase over the ten or so, which were struggling along 10 years ago.

The dominant characteristic of this industry is its explosive growth, not just in the number of organizations, but in its mix, the many foreign competitors, the level of R&D, and the demand for expansion capital. Growth in market volume, both government and private has been matched by an expanding list of product offerings to satisfy new applications, many of which could not have been imagined 10 years earlier.

R & D expenditures, both private and public-funded, are at all-time highs in the USA, Europe and Japan. Yet today's industry remains dominated by technology developed in the 60's. For example, single-crystal, Czochrolski-grown, silicon cells satisfied 90% of the 1979 market. For full realization of the market potential, the PV industry must move ahead with new technologies. But, which technologies? Fortunately, we have several promising alternate material, metalization and encapsulation technologies from which to select.

As a capital-intensive industry, the reluctance to scrap the technology of the 60's is understandable. Corporate investments of $10M in new plant and equipment would be commonplace, with $100M investments not unusual. This need for growth capital has brought about a drastic change in the structure of the industry. With the entry of cash-healthly large companies, independents such as ASEC will face increasing competition. ARCO, Exxon, Shell, Mobil, Phillips are applying sorely needed resources to the capital needs of their new PV partners.

Commercial market position has been, and will continue to be, very much influenced by the new players, whether they be oil company-relatives or government-funded, multi-national, multi-industry giants which may decide that now is the time to enter the commercial market. Leadership of market segments will not be a constant. Solar Power lost its lead in flat-plate sales to Solarex who, in turn, is being challenged by Arco-Solar. While ASEC is at the top in concentrator cell sales today, that lead will be difficult to maintain.

Competitive factors will continue to force vertical integration. The survival of companies involved only at the cell-level is in doubt. For this reason, just about all major cell manufacturers in the industry today are now offering complete systems. This will add to the competitive pressures on the system-only companies and drive them closer to the big decision regarding investment in cell production facilities of their own.

With the funding leverage enjoyed by the U.S. Government in PV - R & D and procurements, the PV industry is quite reactive to any changes in government plans. External, non-industry events such as a change of administration can, and often have, produced drastic redirections. Programs in place today, could be gone tomorrow. Could the MX-RES Program be another B-1? With this in mind, will the PV industry commit to the large investments in new plant and equipment required to meet the relatively short-span MX-RES build-up need? Not very likely! Continued, healthy expansion of the PV industry will depend on the steady, predictable growth of multi-customer markets. Only in this environment can investors be expected to risk their resources. Short-term, program-oriented government needs will likely require partial government investment in production-oriented facilities.

In summary, it's "hard-ball" time for the larger, commercially-oriented companies. Invest at all? If so, when? In what technologies? What degree automation? Where? How credible are the DOE projections regarding PV costs and market size? We are not likely to find one set of answers; But, one up-beat fact stands out. A sizeable commercial market is being successfully worked at today's PV prices and the market is growing. Those companies that can reach this market with attractive prices, adequate capacity and acceptable delivery schedules will reap the harvest.

The real competition of the 1980's may not be for markets. It may well be for the financial resources needed to incorporate 1980's technology and to expand PV output capacity.

PERCEPTIONS AND ISSUES

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The National Photovoltaic Program initiated in 1974 is rapidly approaching its "moment of truth." Namely, can we confidently forecast the day when solar cell technology will meet cost goals that will lead to large-scale, cost-competitive applications? Enormous pressures are mounting to make this answer come out in the affirmative. The RD&D program has made impressive strides. Costs have been reduced; a broad base of research and manufacturing capability is now in place. Expectations of solar advocacy groups, industry and government are high.

After six years of RD&D and hundreds of millions of dollars of effort, one would expect that such a prediction would be relatively easy to make. However, so many interacting factors will influence the answer that it is not clear that a definitive prediction will be possible.

What are some of these factors? First, there is the status of the heavily government subsidized RD&D program. Where do we really stand in developing a mature technology that would have as its next step -- mass production? What sort of market is really ready to accept this technology? Undoubtedly, it will be a multi-faceted market that will look different at different times. What factors will influence this market since we all recognize that a true "free market" does not exist in energy supply? Will tax incentives work? Will PURPA have a significant impact on the way utilities look at new, dispersed energy sources? Can the utilities rapidly accommodate multiple, dispersed, interruptible generating sources such as solar cell arrays?

Answers to these and many more questions will be required before we can confidently predict the future for photovoltaic systems. In the meantime, a stable, predictable RD&D program must be maintained to form the foundation on which the manufacturing industry and potential user community can depend for support and answers. As we attempt to introduce a new technology into the public sector, a process that historically has taken thirty years or more, we should bear in mind that we are hoping to accomplish this in less than half that time.

COMMERCIAL ISSUES AND PRIORITIES FOR ADVANCED MATERIAL SYSTEMS

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The technology base for commercial products offered by the photovoltaic industry today is an offshoot of the extensive material and process information base developed in connection with the evolution of the semiconductor industry. The principal material technology borrowed from the semiconductor industry is Czochralski grown single-crystal silicon. Secondary material technologies extracted include single-crystal gallium arsenide and germanium.

While the single-crystal silicon base in the form of sliced wafers has been sufficient to foster the establishment of commercial photovoltaic ventures, this material technology in its present form does not offer the ultimate economies that will be required if photovoltaics are to impact the bulk energy markets. To realize these ultimate economies either significant modifications of present day single-crystal silicon or alternative material technologies must be identified and developed. Major efforts by both the U.S. government and private industry are being implemented in support of these two approaches.

The number of alternative material technologies under active investigation has increased significantly in the last few years. The purpose of this paper is to review the commercial issues and priorities for advanced photovoltaic material systems. Later in this session status reports on the progress and problems in several promising advanced materials will be presented.

These material options can be classified according to basic material categories, such as:

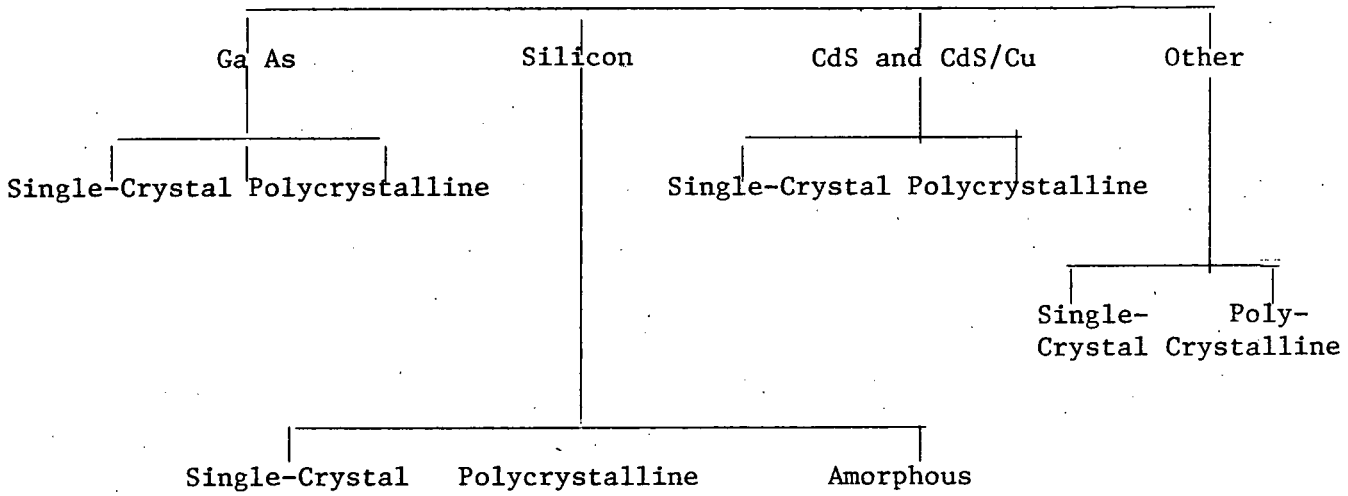
- Silicon
- Gallium arsenide
- Cadmium sulfide
- Other

Industrial firms have directed the major portion of their efforts toward silicon based technologies. A much smaller, but nonetheless significant effort is directed toward the gallium arsenide and cadmium sulfide options. The other material options have been vigorously pursued at university and nonprofit research centers.

An overview of the material options is shown in the attached figure. For commercial products, the single-crystal silicon material using a P-N junction is the most common. Polycrystalline silicon products are just now being introduced, with widespread commercial availability not expected for some time. Amorphous silicon products for low-power applications such as watches, calculators, and clocks are available commercially in Japan. High-power applications, however, are still many years away from incoporating amorphous silicon structures. Commercial availability of gallium-arsenide and cadmium-sulfide based products has not yet occurred. Single-crystal gallium arsenide could be made available on a limited scale if the market for concentrators ever develops. Attempts at commercializing cadmium sulfide have all met with field failure problems. By far, the majority of applications in the foreseeable future will be for flat-plate photovoltaic modules. However, under the proper economic and technical conditions, the demand for concentrator products can

be envisioned.

PHOTOVOLTAIC MATERIAL OPTIONS



There are four principal aspects that can be used to judge the commercial viability of a photovoltaic technology. These include:

- o Material availability
- o Reliability
- o Efficiency
- o Costs

Material availability relates primarily to the commercial availability and the degree to which U.S. resources are available for supplying large quantities of such material. Reliability is associated with the interaction of the photovoltaic product and the terrestrial environment. Efficiency, the rate of conversion of incident energy to electricity, is associated with long-term expectations rather than the immediate or present-day status of the material. Costs deal principally with the material aspects but also include cell preparation and packaging requirements.

The following speakers in this session will provide information on these important criteria for advanced materials. Their results will play an important role in setting the priorities for further development and subsequent commercialization activities.

THIN-FILM POLYCRYSTALLINE SILICON: PROGRESS AND PROBLEMS

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Thin-film polycrystalline silicon solar cells offer a potential low-cost alternative to single crystal silicon solar cells, while maintaining the attributes associated with silicon: viz., abundance, relatively high efficiency, stability, and the existence of a broad technology base. The research efforts over the past several years have resulted in the achievement of relatively efficient (>10%, AM1), large area (>1 cm^2) solar cells by a number of potentially low-cost approaches. Based on the demonstrated results on cell efficiency, cell area, stability and low-cost potential, SERI has initiated during 1980, as part of the DOE Photovoltaics Advanced R&D program, the "Exploratory Development of Thin-Film Polycrystalline Silicon Photovoltaic Devices." The objective of this Exploratory Development program, and of a subsequent Technology Development phase to be initiated in 1983, is to demonstrate a module cost feasibility of <$500/peak kWe (1980 $) in 1986 for polycrystalline silicon solar cells.

Questions which frequently arise in connection to thin-film polycrystalline silicon solar cells relate to the definition of the term "thin film" and to the effects of grain size. Since both the performance and the cost of the solar cell involve, in a rather complicated manner, the variables of film thickness and grain size, a clear answer to these questions is not possible. Theoretical modelling [1] has indicated that grain sizes of at least 150 μm will be required for >10% efficient solar cells; smaller grain sizes will require some form of passivation of grain boundary effects. Preliminary cost/performance considerations suggest that film thicknesses of <100 μm will be required; this is the stated goal of the Exploratory Development program.

Progress in polycrystalline silicon solar cell research has occurred in the areas of thin-film material and cell development, and in the basic understanding of the effects of grain boundaries and the passivation of these effects. Figure 1 summarizes the historical improvement in the efficiency of polycrystalline silicon p-n junction solar cells; the figure only shows those approaches which have the potential to meet the goal on film thickness (< 100 μm). The results on bulk polycrystalline silicon wafers (e.g., Wacker, Semix) are excluded from the figure.

Thin silicon sheets have been grown directly from the melt in the form of both unsupported and supported sheets. Motorola's approach [2] of either chemical vapor deposition (CVD) or energy beam deposition (EBD) of a thin silicon film on a temporary molybdenum substrate, followed by ribbon-to-ribbon (RTR) recrystallization of the shear separated film, has recently resulted in cell efficiencies of 13% for CVD/RTR and 12% for EBD/RTR. Novel unsupported sheet techniques which have received attention recently include horizontal ribbon growth [3], edge-supported pulling [4] and roller quenching of silicon ribbons [5]; of these techniques, only roller quenching is likely to have the potential to produce silicon sheets of <100 μm thickness. Thin silicon sheets have been grown from the melt on supporting substrates such as mullite by the silicon-on-ceramic (SOC) process [6] and graphite by the ribbon-against-drop (RAD) process [7]; the solar cell results for these techniques are summarized in the figure. A feature of these melt growth techniques is that grain sizes of several 100 μm are readily achievable; the exception is roller quenching which produces a fine-grained (~30 μm) polycrystalline structure.

There have been extensive investigations of silicon film growth by various physical and chemical vapor deposition processes (PVD or CVD). These techniques require the use of a substrate which is selected based on various physical (e.g., thermal expansion, crystallinity), chemical (e.g., reactivity, impurities) and electrical (e.g., conductivity, ohmic contact), as well as economic

considerations. A result which has emerged from these researches is that relatively high efficiency (>10%) thin-film silicon solar cells can be fabricated by the epitaxial growth of a 15 to 30 μm silicon layer on a large grain size polycrystalline silicon substrate. The epitaxial films are usually grown by CVD; the p-n junction can be formed either by changing the doping during CVD or by conventional diffusion. The low-cost potential of this approach lies in the fact that the polycrystalline silicon substrate may be of a much lower purity (e.g., metallurgical grade) than the semiconductor grade silicon used in the melt growth approaches to silicon sheet. Extensive investigations have been carried out on techniques to purify metallurgical grade silicon and to produce low-cost polycrystalline silicon substrates for epitaxial growth. The historical evolution of the epi/mg-Si technology at SMU [8] and RCA [9] is shown in the figure. Another result which has emerged from the research studies is that vapor growth of silicon on foreign substrates (i.e., non-epitaxial deposition) does not result in an adequate grain size in the silicon film. The combination of small grain size and impurity incorporation during PVD or CVD growth has limited improvements in cell efficiency by these approaches (see figure).

Other novel silicon film growth techniques which have shown encouraging results recently include the electrodeposition of silicon from molten salt electrolytes and the electrohydrodynamic deposition of silicon. The former has resulted in thin-film deposits with up to 100 μm grain size [10]; in the latter, a controlled stream of ionized melt droplets was used to deposit a silicon film [11].

Basic studies of polycrystalline silicon solar cells have been concerned with: (i) the characterization of the structural, compositional, electrical and optical properties of polycrystalline silicon and correlations to cell performance; (ii) theoretical modelling of photovoltaic mechanisms in various solar cell structures in polycrystalline silicon; and (iii) development of techniques for reducing or eliminating the deleterious effects of grain boundaries. Notable achievements include the development of various experimental techniques to characterize the effects of grain boundaries, the theoretical demonstration that small areal inhomogeneities can cause severe degradation in solar cell performance, and the experimental demonstration of grain boundary passivation by H-plasma treatment and by selective dopant diffusion at grain boundaries. A weakness in many of these researches is that the material studied is bulk polycrystalline silicon rather than the thin-film materials of interest.

Current concerns in thin-film polycrystalline silicon solar cell development relate to the scalability and reproducibility of the more promising approaches, the reliability and stability of the cells and modules, and an assessment of the low-cost potential of the technologies. The resolution of these concerns is the objective of the Exploratory Development program. Continued research activities are needed, however, to identify and develop alternate promising technologies, and to provide basic research support for the advanced development efforts.

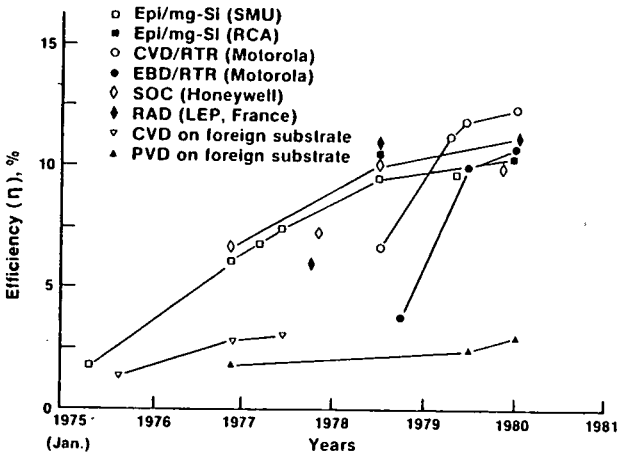


Figure 1: Efficiencies of polycrystalline silicon p-n junction solar cells.

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CADMIUM SULFIDE SOLAR CELLS: PROGRESS AND PROBLEMS

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The definition of a thin-film solar cell is to some extent arbitrary but a device having active layers less than 5 μm thick will serve. For such devices to have high efficiency the semiconductor absorbing photons and producing minority carriers must have a high absorption coefficient above the bandgap, preferably in excess of 10^4 cm^{-1}. The first thin-film solar cell with significant efficiency was the CdS/Cu_2S heterojunction discovered in 1954 by Reynolds. Cu_2S has in fact one of the highest absorption coefficients known, exceeding 4 x 10^4 cm^{-1} over most of its absorbing range. Early development of the cell was undertaken in America for space applications and in Europe key fundamental work was conducted in Holland, Germany and France. These research efforts established that the preferable Cu-S phase was chalcocite, in which most of the light generated current is formed. The majority of the voltage drop is across the copper compensated region in the CdS layer. Although there were a number of reports of relatively high efficiency, the majority of cells produced were of low efficiency and most groups experienced difficulty in developing a reproducible production procedure. A further major problem with most of the cells was the rapid loss in performance which was identified as either due to oxidation or electrolytic decomposition of the Cu_2S layer.

In 1972 a program of cell development was initiated at the University of Delaware to develop a low-cost solar cell for terrestrial applications. A combination of materials studies and controlled device formation resulted in a progressive improvement in conversion efficiency culminating in a maximum efficiency of just over 9% recorded in 1978. During this work, a substantially improved understanding was achieved of both the structure and operation of the cell. It became clear in about 1975 that the parameter limiting the achievable cell conversion efficiency was the open circuit voltage, which is effectively pinned at about 0.5 V by the electron affinity mismatch between Cu_2S and CdS. Analysis of the operation of the cell, confirmed by preliminary experimental work in France, shows that utilizing a solid solution of (CdZn)S in place of the CdS should give higher voltages without any overt reason for anticipating a loss in either fill factor or short circuit current. However, the first (CdZn)S/Cu_2S cells did show a drastically reduced short circuit current and also generally poor fill factors and many of the early cells also displayed a decay in open circuit voltage with time.

Modifying the production of the (CdZn)S to give a semiconductor with properties very similar to the CdS in high efficiency cells has resulted in a progressive improvement in short circuit current and fill factor. Specific parameters which must fall within narrow ranges are the grain structure of the material, the resistivity, and the photoluminescence. Recent (CdZn)S cells containing between 15 and 25% zinc have currents only about 10% below the highest achieved with CdS/Cu_2S. Fill factors have also improved so that efficiencies of 9.5% have now been achieved and values in excess of 10% seem to be very likely and 14% is plausible.

The early reports of low stability in CdS/Cu_2S were certainly largely due to oxidation of the Cu_2S layer. This layer is only ~ 0.3 μm thick and the formation of one monolayer of oxide is sufficient to increase the carrier concentration from an optimum value of $\sim 10^{18}/cm^3$ to a value of $10^{20}/cm^3$ at which the short circuit current will have been reduced by ~ 50%. From a review of the available data it is concluded that long-term cell stability is achievable by total hermetic encapsulation. The high efficiency cells made at IEC have been subject to heat treatment at temperatures in the range of 150 to 170°C for periods in excess of 100 hours indicating adequate thermodynamic stability for long-term deployment at temperatures of the order of 60°C. The electrolytic decomposition of Cu_2S requires a voltage drop across it of > 0.35 V and as the Cu_2S in a high efficiency cell supports virtually no potential drop, this mode of failure should not occur. A limited number of tests at IEC and elsewhere have shown that at least some CdS/Cu_2S cells can be operated at maximum power point or open circuit voltage without significant loss in performance.

A number of commercialization efforts are already under way in America and elsewhere. SES, Inc., a subsidiary of Shell Development Company and Photon Power, Inc., have been established for the purpose of manufacturing CdS/Cu_2S cells. In Germany a pilot line is in operation at the Universtiy of Stuttgart under the direction of W. M. Bloss. At the Institute of Energy Conversion, a Unit Processing Laboratory has been established and with support from Chevron Research a continuous deposition process for the CdS layer is being developed. Future efforts will be aimed at developing production technologies for the other steps in the manufacture of large area CdS/Cu_2S cells. A complete cost analysis of the continuous production of CdS/Cu_2S cells has been carried out at IEC indicating that an ultimate cost between 16 and 25¢/Watt should be achievable.

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AMORPHOUS SILICON
PROGRESS AND PROBLEMS

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Amorphous silicon hydrid is an interesting candidate material for thin film photovoltaics because the cost of the material itself is very low. The table below compares the manufacturing cost of a specific amorphous silicon panel with the cost of manufacturing a specific crystalline silicon panel based on 6" diameter cells. As can be seen from the table, the principal cost difference is in the formation of the light active layer, which in this comparison and for both cases, includes the silicon materials cost. There are, however, cost savings throughout the process associated with the thin film panel. These savings are due to the ability to pattern the thin layers involved.

The comparison just described is optimistic in both the amorphous and crystalline cases. However, the level of optimism is comparable. What is not comparable is the nature of the problem facing the development in each of the areas. The factors affecting the performance of the crystalline devices are well understood. The material and processing requirements have been well documented. The efficiency assumed in the comparison (14%) has been experimentally demonstrated. In the case of amorphous silicon, as fundamental a problem as by what mechanism the minority carriers move through the material is unknown. It is not an easy task to predict what future improvements (from the experimental 6% to the required 10%) will result since present limitations are not understood. Attainment of the manufacturing cost for the crystalline panels requires less inspiration than similar success in the amorphous area.

Recent improvement in the performance of moderate area cells (greater than 1 cm^2) has lead us to an investigation of large area fabrication techniques and the beginning of a formal life test effort. The current status of this effort will be reviewed.

COMPARATIVE MANUFACTURING COSTS

Fabrication Stage	2 ft. x 4 ft., 10% eff. amorphous silicon $/$W_p$	6" wafer 2 ft. x 4 ft., 14% crystalline silicon $/$W_p$
Form Front Contact & AR	.025	.052
Form Light Active Structure	.060	.327
Define Device Geometry	.014	.004
Form Back Contact	.011	.088
Test	.005	.001
Form Laminated Module	.097	.197
	.21 $/$W_p$	.67

PROMISING NEW PHOTOVOLTAIC MATERIALS

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Only five materials systems in any form have given greater than 10% solar efficiency as a photovoltaic solar cell: those based on silicon, gallium arsenide, indium phosphide, copper indium selenide, and cadmium telluride. In this paper we focus on just two materials: cadmium telluride (CdTe), because work over the past six years has indicated that it is promising, and zinc phosphide (Zn_3P_2), because it is a new material that shows the potential for being promising. Both are direct bandgap materials with bandgap near 1.4 eV, the optimum for solar energy conversion. Both can be made p-type readily in both single crystal and thin film form.

Of the six chalcogenides of Zn and Cd, only CdTe can be made high conductivity in both n- and p-type. Because of its direct bandgap, only about 2 μm of CdTe are required to absorb over 95% of the terrestrial solar spectrum. Therefore, although most junctions made to date have involved single crystal material, the greatest potential for CdTe is as the absorber component of an all thin-film solar cell. If CdTe is used as the light-absorbing member of a heterojunction, then a large bandgap material is needed for the other member of this junction, which must be readily capable of preparation in high-conductivity n-type form. These considerations have led to the investigation of CdS, Indium-Tin Oxide (ITO), and ZnO as representative large bandgap window materials. These films may be typically deposited by any one of a variety of techniques including close-spaced vapor transport (CSVT), vacuum evaporation (VE), chemical vapor deposition (CVD), rf sputtering, or spray pyrolysis. The most promising techniques for the deposition of CdTe films are CSVT and hot-wall VE, both of which achieve a planar geometry for film deposition.

The Table on the following page shows major achievements of recent years on solar cells based on CdTe. Surprisingly little work has been done on CdTe p-n homojunctions per se; the work of Mimila-Arroyo et al. listed in the Table represents the major solar cell work of this type. Most of the homojunction responses listed in the Table (Yamaguchi, Nakayama, Courreges) are cases of a buried homojunction formed intentionally or unintentionally during the junction formation process; this occurs by impurity doping of the substrate surface in the case of Yamaguchi and Nakayama, and by rf sputtering damage of the substrate surface in the case of Courreges. There is a general tendency for homojunctions to have a higher open-circuit voltage V_{oc} and a smaller short-circuit current J_{sc} because of front-surface recombination losses.

The Table shows that solar cells involving CdTe with efficiency of 8% or greater have been made with six different cell fabrication processes: CVD, screen printing, VE, CSVT, spray pyrolysis, or rf sputtering. Success with all thin-film CdTe cells will probably be challenged by development of suitable methods for deposition of high-conductivity p-type CdTe films, formation of low-resistance ohmic contacts to p-type CdTe, and limitations to diffusion length of electrons in p-type

Materials	Junction Type	Structure	V_{oc},V	J_{sc},[a] mA/cm^2	Efficiency, %	Year	First Author
CdTe/CdS	hetero	CSVT p-CdTe on xtal CdS	0.61	14	4.0	1974	Fahrenbruch
CdS/CdTe	homo	CVD CdS on xtal CdTe	0.67	18.4[b]	12.0	1976, 1977	Yamaguchi
CdS/CdTe	homo	screen printing	0.69	31.1[c]	8.1	1976	Nakayama
CdS/CdTe	hetero	VE CdS on xtal CdTe	0.63	16.1	8.0	1977	Mitchell
CdS/CdTe	hetero	spray CdS on xtal CdTe	0.53	16.4	6.5	1977	Ma
ZnCdS/CdTe	hetero	spray ZnCdS on xtal CdTe	0.79	12.7	7.8[e]	1978	Yin
CdTe/CdTe	homo	ion implant in xtal CdTe	0.84	6.5	3.0	1978	Chu
CdTe/CdTe	homo	CSVT p-CdTe on xtal CdTe	0.72	12	7.8	1979	Mimila-Arroyo
ITO/CdTe	homo	rf sputter ITO on xtal CdTe	0.82	14.5	8.0	1980	Courreges
ZnO/CdTe	hetero	spray ZnO on xtal CdTe	0.54	19.5[d]	8.8	1980	Aranovich
Mg/Zn_3P_2	Schottky	VE Mg on xtal Zn_3P_2	0.50	19.0	6.1	1979	Catalano

[a]Illumination of 85 mW/cm^2 except (b) 68 mW/cm^2, (c) 140 mW/cm^2, (d) 100 mW/cm^2.

[e]Four-point contact measurement to eliminate contact resistance.

CdTe. The common problem of all thin-film cells, increased forward leakage current reducing the open-circuit voltage must also be faced.

Pioneering work on the development of Zn_3P_2 has been done by the group at the Energy Conversion Institute in Delaware. The material is p-type as grown, probably due to phosphorus interstitials; the existence of n-type material is still uncertain. The elements involved in Zn_3P_2 are readily available and inexpensive. Ohmic contacts can be made with either silver or silver/gold alloy. The index of refraction is about 3.6, but the relatively high reflectivity of an air/Zn_3P_2 interface need play no serious role in a back-wall heterojunction cell based on Zn_3P_2. Iron appears to be a promising substrate for thin-film Zn_3P_2, since it has similar lattice constant and thermal coefficient to Zn_3P_2. Schottky barriers have been prepared on Zn_3P_2 with Mg or Al, with the photovoltaic results summarized above in the Table; a barrier height of about 1.1 eV is found for Mg, although the exact phenomena occurring at the interface are still being investigated. Estimates of the electron diffusion length in Zn_3P_2 give encouraging values of a few micrometers. No even moderately efficient heterojunction cell has to date been prepared on Zn_3P_2. The material is fairly sensitive to heat treatment, decreasing in resistivity for heating in H_2 and increasing for heating in vacuum.

PROGRESS AND PROBLEMS IN THE DEVELOPMENT OF ADVANCED SOLAR CELL MATERIALS

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Research on advanced solar cell materials has been greatly expanded during the past two years as a result of increased government funding. The Solar Energy Research Institute, under contract to the U.S.Department of Energy, is managing and conducting research on a wide variety of advanced photovoltaic materials and concepts to develop low cost solar cells (i.e. $0.15 to 0.40/Wp modules in 1980$). The emphasis of the program is on thin film and electrochemical cells with conversion efficiencies greater than 10% and multijunction concentrator cells with conversion efficiencies greater than 30%.

Conversion efficiencies of greater than 10% have been demonstrated for "thin film" polycrystalline cells made by several different techniques. These include edge-supported pulling, ribbon-to-ribbon, and silicon on low-cost substrate technologies (1). As a result, some of these technologies have advanced to exploratory development where their feasibility for achieving the cost goals will be investigated. MIS and SIS cells with conversion efficiencies greater than 10% on cast polycrystalline silicon have also been achieved (2). These efficiencies are, however, less than the best p-n junction efficiencies on comparable materials. Grain boundary characterization has provided some clues to material performance and grain boundary passivation in silicon and other materials. Further work on grain boundary passivation is continuing to improve polycrystalline cell performance. The expanded research on amorphous silicon has provided new information on the roles of impurities and has resulted in cell efficiencies greater than 6% over areas greater than $1cm^2$ (3). The addition of flourine has significantly improved the effective doping of n type material thereby dramatically increasing the conductivity of this layer. Improvement in the short circuit current and fill factor of p-i-n structures has led to the improved efficiencies for the larger areas.

The conversion efficiencies of Cu_2S/(CdZn)S and $CuInSe_2$/CdS cells have increased significantly. Cells made from Cu_2S/CdS, Cu_2S/(CdZn)S and $CuInSe_2$/CdS all exhibit efficiencies in excess of 9%. The $CuInSe_2$/CdS cell without optimization and material thicknesses of only a few microns has a conversion efficiency near 9.4% for a $1cm^2$ cell (4). The long term stability of these types of cells remains to be demonstrated. Reproducibility of cell characteristics over large areas and low cost processing must also be achieved for these cells to reach the cost goals.

Thin film GaAs cells are being investigated by two approaches. One approach, which is concerned with the growth of thin film polycrystalline cells on low-cost foreign substrates, has yielded cell conversion efficiencies of greater than 8% over a $9cm^2$ area (5). The open circuit voltage is disappointingly low compared to single crystal cells. This requires further research to understand the mechanism and improve the cell performance. The second approach is aimed at growing thin (a few microns) single crystal films on reusable or low-cost substrate. GaAs cells with efficiencies greater than 15% have been fabricated on a reusable substrate (6).

Other thin films, notably Zn_3P_2, InP and CdTe are being pursued, and show varying

degrees of promise for efficient photovoltaic conversion at low cost. InP films have recently been grown on CdS/ITO/Glass substrates with a large grain size (50μm) compared to the thickness (2-4μm). Devices made from this material have a V_{OC} ≈600mv (7). Zn_3P_2 thin films have been grown on a carbon coated iron substrate with diffusion lengths of approximately 2μm. An efficiency of approximately 6% for an all thin film 0.7cm^2 device was obtained with little apparent degradation due to grain boundaries as determined by EBIC measurements (8). P-N homojunction or heterojunction devices need to be developed to increase the efficiency and provide stable devices at a reasonable cost. The research on CdTe cells consists of a variety of methods for fabricating device quality material. To date thin film cells of approximately 2% efficiency have been made by chemical spraying (9). Considerable research needs to be done to improve the resistivity and transport properties of CdTe.

Research on photovoltaic electrochemical (PEC) cells has progressed rapidly as conversion efficiencies and stability have shown significant improvement for several electrode materials. Efficiencies with single crystal GaAs electrodes of 12% (10) have been observed, while thin film CdSe electrode configurations have demonstrated efficiencies greater than 6% (11). Single crystal $MoSe_2$ cells with efficiencies of 7.5% (12) have been stable for several months, but cell stability remains an area for increased research. In-situ storage of PEC cells using several configurations is also being investigated.

In concentrator cell research, the cascade action of pnn^+p^+AlGaAs/pnGaAs multi-junction cells has been demonstrated. Several material systems with better potential are also being explored. Luminescent concentrators, while still at a low efficiency (3.2%), continue to show improvement (13). Two degradation mechanisms have been identified. The rapid degradation mechanism appears controllable while the long term mechanism does not appear serious for many applications.

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SILICON SOLAR CELL MANUFACTURING: STATUS AND FUTURE POSSIBILITIES

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During the past five years the Low-Cost Solar Array (LSA) Project at the Jet Propulsion Laboratory has directed efforts to reduce the cost of manufacturing photovoltaic solar modules. Within the LSA Project it has been the task of the Production Process and Equipment Development Area (PP&E) to integrate applicable information and experience obtained by other areas of the Project, i.e., Silicon Material, Large Area Silicon Sheet, Encapsulation, Engineering, and Operations.

To obtain detailed cost information required to evaluate processes and make reasonable trade-offs during development, a standardized procedure for determining array manufacturing costs was devised (1). The method (SAMICS) is implemented by use of a computer program; previously SAMICS was implemented manually by IPEG (2), a system which identifies specific overhead cost factors by which direct requirements (labor, capital equipment, factory floor space, and combined utilities, supplies and materials) are multiplied to obtain total costs.

In 1977 the PP&E Area developed a hypothetical candidate processing sequence (3) for producing solar modules at a cost of $2.00/W ($2.80/W in 1980 dollars). The following year another candidate sequence was selected (4), this one with production costs of $0.50/W ($0.70/W in 1980 dollars). Both sequences were evaluated using SAMICS methodology, and each was presented as a "strawman" for industry to consider.

The state-of-the-art of photovoltaic module manufacturing has progressed significantly in the last five years. The industry has grown in harmony with LSA Project developments; larger diameter wafers, glass encapsulants, and several newer lower-cost processes are now used. If a composite of state-of-the-art processing is compared with the $2.80/W and the $0.70/W sequences, some interesting differences emerge. Table 1 shows some of the key statistics. These values were calculated using data gathered from manufacturers that are estimated to be the six largest in the industry today. The total production rate (3.14 MW/yr) is not the total sold over the past year, but the current production capability continued for a year. Less than half the production comes from Czochralski crystals grown and sliced in-house; the major portion comes from silicon wafers purchased from the semiconductor wafer market. For this reason, the silicon slice cost is separated from production costs of cell and module manufacturing. To obtain the total cost of each of these sequences, the cost of capital equipment, floor space, and other costs associated with silicon slice manufacture must be

Table 1. Manufacturing Sequence Statistics (not including silicon sheet formation)

	1980 Status	$2.80/W Sequence	$0.70/W Sequence
Production Rate (MW/yr)	3.14	20	250
Direct/Ind. Labor (persons)	988	157	673
Watts/year/person-hr	1.44*	61.5**	179**
Manufacturing Space (ft^2)	141,000	35,500	72,080
Watts/year/ft^2	22.3	563	3,468
Floor Space/person (ft^2)	142.7	226	107
Capital Equipment ($)	8,583,000	8,000,000	8,219,000
Watts/yr/Capital $	0.366	2.50	30.42

*Based upon 44-hr week (2200 hr/year/person)
**Based upon 2070 hr/year/person

The work described in this abstract was conducted at the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the U.S. Department of Energy through an agreement with NASA.

added as follows: 1980 Status = $5.00/W; $2.80/W Sequence = $1.90/W; $0.70/W Sequence = $0.248/W.

Examination of these statistics shows that although capital equipment costs for all three module manufacturing sequences are essentially the same, the productivity is increased by factors of 6 and 80, or 1½ and 20 if we correct for the recommended four shifts (around the clock seven days a week). This suggests that current capital equipment is underutilized but that productivity is within 33% of that estimated in the $2.80-per-watt sequence.

The current manufacturing space is approximately four times as great as that required to accomodate the capital equipment for the $2.80/W sequence. This is in part an outgrowth of excess in-line inventory due to the great variety of product options. Excess floor space means that capacity expansion can occur rapidly, but it also increases today's product cost.

The number of people presently employed is far too great to be justified by current output. Looking at productivity (watts/year/person-hour), one sees factors of 43 and 124 in glancing across the Table 1 sequences. Several things account for this apparent inefficiency of labor, most notably the current involvement of industry in engineering, design, and process experimentation. Moreover, the many design and process changes make it difficult to stabilize the manufacturing yield and to reduce waste and rework.

By judicious extrapolation of the equations in IPEG it is possible to make comparisons of the dollar-per-watt contributions of the various cost elements. The current 1980 cost of utilities and supplies is taken from Reference 4. The accuracy claimed for these calculations is ± 20% but several comparisons with detailed SAMICS calculations show about half this tolerance. These data are shown graphically in Figure 1. The IPEG 2 estimation of $19.03/W for state-of-the-art modules may be a little high, indicating that current industry has found means of cutting costs which are not in the IPEG equation. Government-sponsored R&D is currently a significant part of the industry's business, and this tends to reduce the overhead.

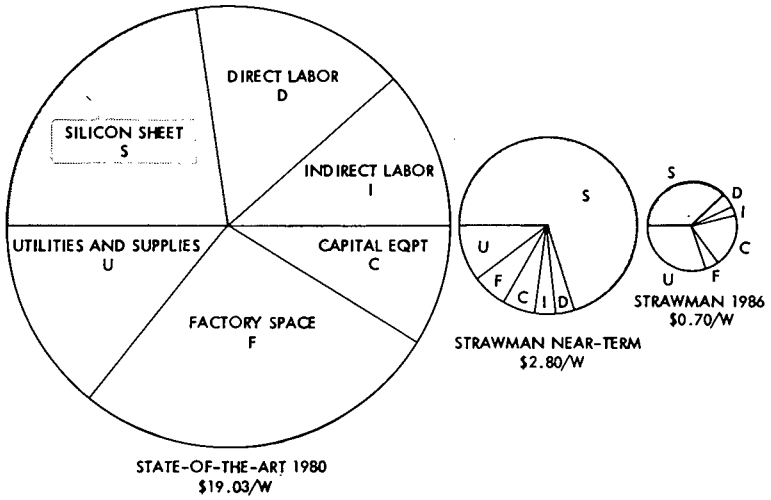


Figure 1. Relationship of Costs for Selected Manufacturing Sequences

Although industry currently seems to be focused upon reducing silicon and silicon wafer costs, comparison of cost areas shows that an increase in productivity through multiple labor shifts and a reduction in floor space will make a much greater difference in the near term. The next step, to $0.70 per watt, is shown dramatically to depend upon the silicon sheet cost.

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ASSESSMENT OF DISTRIBUTED PHOTOVOLTAIC ELECTRIC POWER SYSTEMS

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Purpose and Scope The JBF Scientific Corporation has completed a two-year study for the Electric Power Research Institute that was aimed at assessing the potential of distributed photovoltaic (PV) electric power systems and comparing them to central power station configurations. The purpose of the study was to determine the technical and economic potential of distributed PV electric power systems in the United States by 1995 and to assess their probable impacts on utility systems.

Participating Utilities Three utility systems from three different regional electric reliability councils participated in the study: Northeast Utilities Service Company, Alabama Power Company, and the Los Angeles Department of Water and Power. In addition, two synthetic utilities (as defined in EPRI Report EM-285, February, 1977) were also selected for analysis. One synthetic (Scenario E) which is representative of the Southwest was selected to broaden the geographic coverage of the systems analyzed. The other (Scenario F) typifies the Northeast region and was selected in order to allow comparison of results for an actual and synthetic utility.

Study Methods The economics and utility impacts of distributed PV systems were evaluated by using a combination of hourly performance simulation models, utility production cost models, and economic models based on life-cycle analysis. For both utility- and customer-owned cases, the analysis focused upon determining the potential value of the distributed PV systems to the owner. Once determined, the value could then be compared to estimated system cost projections to judge economic potential.

For customer-owned PV systems a method of determining savings without using an explicit rate structure was employed. Instead, the customers' savings were based upon the savings that the utility would potentially experience as the result of the installation of distributed PV systems.

From the utility point-of-view the economic impact related to distributed PV systems may be derived from five sources: (1) reduced fuel consumption, (2) reduced operating and maintenance (O&M) costs, (3) decreased revenues, (4) capacity credits due to deferrals of new generating capacity additions, and (5) potential effects on T&D systems. All five were investigated in various scenarios for distributing the PV systems.

For the cases where PV systems were located at utility customers' facilities, four types of customers were defined in terms of their load shapes: a single-family residence, a load-center consisting of a group of residences, a commercial establishment, and an industrial establishment. In general, the analyses were aimed at determining the value of the PV systems to the owner (utility or customer) and their impacts on the utility irrespective of ownership.

Utility subtransmission and distribution system impacts were assessed by defining representative urban, suburban, and rural distribution networks and determining the effects of various levels of penetration of distributed PV systems.

Principal Findings The key findings can be divided into three groups: (1) those that relate to the potential value of distributed PV systems, (2) those that relate to the potential penetration and utility impacts of customer- or utility-owned distributed PV systems, and (3) those that relate to potential T&D impacts. All of the findings are of course subject to the qualification that they have been developed from the base case analyses which were based upon a complex set of assumptions and procedures. The results also depend upon the assumptions that photovoltaic array costs in 1995 will be about in the mid-range of the Department of Energy's cost goals and that the balance of PV system costs will be commensurate with high volume manufacturing and construction rates. Key findings related to penetration and utility impacts, for example, are as follows:

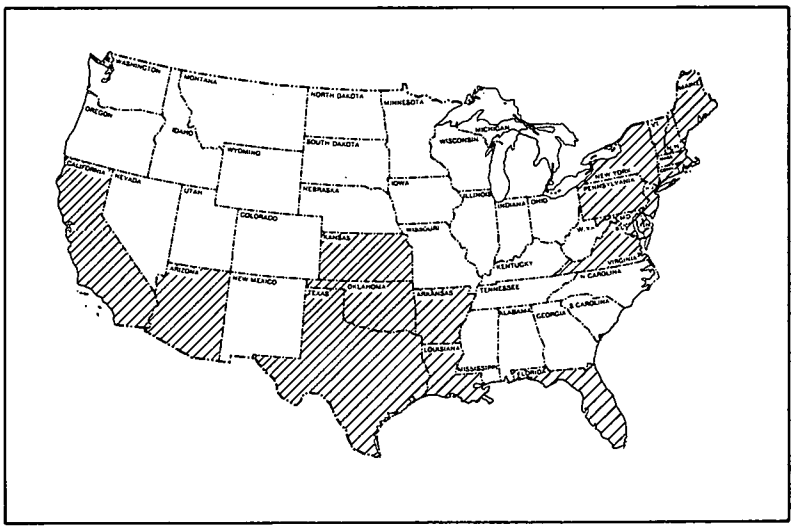


Figure 1. Regions in Which Distributed Photovoltaic Systems May Have High Economic Potential in 1995 (Shaded Area)

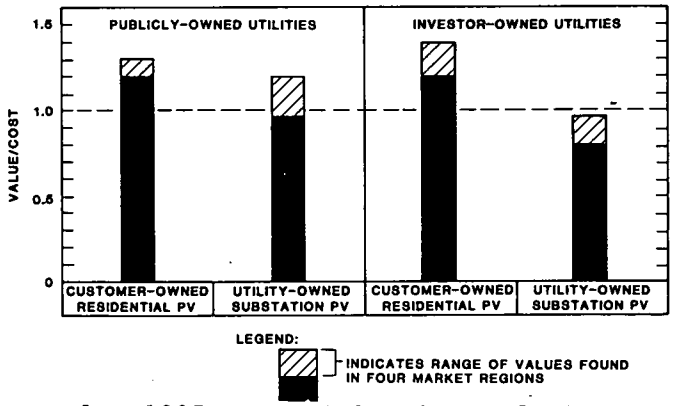


Figure 2. 1995 Potential Values of Distributed Photovoltaic Systems in the California-Arizona Region

- There are four market regions comprising 21 states in the (contiguous) United States in which certain distributed PV systems may show potential economic viability by the year 1995. These are shown on the map, Figure 1.

- If owned by the customers, distributed PV systems for individual residences and residential load centers show potential economic viability by 1995 in all four market regions identified.

- In three of the four market regions identified, PV systems, owned by utilities, and distributed about their T&D networks show potential economic viability by 1995. Figure 2 shows the range of potential 1995 value-to-cost ratios for distributed PV systems in all four regions for both types of ownership.

- The potential for distributed PV systems to significantly impact the utility industry as a whole by 1995 is limited.

- To accomplish relatively modest penetrations of residential and utility-owned distributed PV systems in the market regions identified would require a substantial increase in the industrial production capacity for PV systems.

ROOF INTEGRATED MODULE DESIGN

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Late in 1978, Jet Propulsion Laboratory, under its on-going "Low Cost Solar Array Project," requested proposals for the development of "Third Generation Residential Modules." ARCO Solar, in response, chose to go beyond the implied requirements for such a module, and integrate photovoltaics into a standard roofing system.

With the aid of Architectural Consultant, Richard Schoen, Director of Architecture, Solar Resources, Inc., ARCO began the task. While Schoen and his organization studied various roofing systems, ARCO engineers undertook the task of solving a miriad of technical problems such as developing an inexpensive method of cell encapsulation, automated cell interconnects and environmental testing that would lead to the choice of suitable materials that could last the usual architectural life expectancy of 20 years.

It became obvious to Schoen that a roofing system as old as eighteen century Paris and as new as the most current custom-designed residences - the batten-and-seam roof - would be the best choice.

This familiar roof used long sheetmetal trays with up turned edges. These trays are held to the subroof usually building-paper covered plywood sheeting, by means of clips. These clips also retain adjacent trays and establish spacing between trays. The spaces, stretching from roof ridge to eave, are covered in contemporary versions, by snapped-into-place metal battens. Similar ridge, eave and valley trim completes the conventional roof.

The overall architectural expression is one of vertical lines (ridge to eaves) approximately 2" in width, separating flat roof panels. Approximately 20" in width. With the use of modern plastics such as DuPont Tedlar, laminated to the sheetmetal panels, a wide selection of colors are available. Having chosen batten and seam, ARCO Solar Engineers began the detail task of integrating the photovoltaics cells.

The results of this effort has produced a module that has the following configuration:

1. A 24 gauge galvanized steel substrate with a 4 mil thick pigmented layer of DuPont Tedlar laminated to its outer surface. An epoxy wash is applied to the under surface for added protection.

2. A 4 mil layer of ethylene vinyl acetate (EVA) as a pottant.

3. 3 parallel strings of 20 photovoltaic cells.

4. Another layer of EVA.

5. A 3 mil layer of clear DuPont Tedlar.

The dimensions of this module are approximately 21" wide x 48" long. When installed, each module overlaps the lower approximately 7".

The module inter-connects and all external wiring to the power conditioning equipment fit neatly into the space between the modules and are covered by snap-in-place battens. It is not necessary to penetrate the subroof. All wiring is brought down from the roof via external conduit.

Installation of the first residential system was completed, using a model home in Phoenix, Arizona, on May 15, 1980. This house has provided invaluable data for the design of the current installations in Hawaii.

PHOTOVOLTAIC CONSENSUS STANDARDS

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The development of consensus standards for photovoltaics has become an area of intense interest. The American Society for Testing and Materials (ASTM) has a subcommittee which presently has six photovoltaic standards under development. The Institute of Electrical & Electronic Engineers (IEEE) also has recently started developing photovoltaic standards.

The paper will first address the consensus standard process in general terms. The coordinating activities of ANSI (American National Standards Institute) will be explained. A brief statement will be made regarding the various organizations involved in the development of solar energy standards.

The bulk of the talk will concentrate on a discussion of current activities within ASTM on photovoltaic standards development. ASTM currently is in the process of writing five standards related to the testing and reporting of flat plate, non-concentrator photovoltaic device performance. The five standards are:

- Methods of Testing Non-concentrator Terrestrial Photovoltaic Devices Using Reference Cells
- Specification for Non-concentrator Terrestrial Photovoltaic Reference Cells
- Specification for Solar Simulation Performance for Terrestrial Photovoltaic Testing
- Methods for the Calibration of Non-concentrator Terrestrial Photovoltaic Reference Cells
- Method for Determining Spectral Response of Photovoltaic Devices

A description and brief summary of each standard will then be given.

Test Method: The test method, which uses a reference cell method for measuring effective solar irradiance, defines methods for testing single cells, modules, and arrays in natural sunlight and with solar simulation (pulsed and continuous). An important aspect of the standard is a definition of the reporting conditions which must be used in reporting the measured performance.

Reference Cell Specification: This standard is a specification of the physical requirements for a photovoltaic reference cell. Included in the specification is a description of packaging requirements.

Calibration of Reference Cells: This is a test method to define how to calibrate (and thus create) Type I and Type II reference cells. It also defines the method for determining the temperature coefficient of the cell.

Solar Simulation Specification: This specification defines the performance characteristics of various classes of solar simulation used for indoor testing of

photovoltaic devices, including spectral uniformity, temporal stability, and spectral accuracy.

Spectral Response: This is a test method which will define how to measure spectral response of photovoltaic devices.

In addition to the five standards regarding non-concentrator devices ASTM is developing a corresponding test method to measure and report performance of concentrator photovoltaic devices.

The talk will conclude with a brief discussion of future work anticipated within ASTM and IEEE.

PHOTOVOLTAIC SYSTEMS DEVELOPMENT: AN OVERVIEW

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The U. S. National Photovoltaic Program is nearly six years old. During this time numerous technical and engineering advances have brought photovoltaic systems even closer to commercial competitiveness. In addition to the reduction in subsystem costs, there has been an increase in the understanding of systems operation and the requirements of potential applications. This latter progress has been brought about through numerous analysis studies and field testing experience. The remainder of the papers in this session will address these issues in detail for each of the application sectors. The purpose of the present work is to provide a brief overview of the results, showing the general trends, to serve as an introduction to those later papers.

Photovoltaic systems can be divided into two general classifications with markedly different characteristics and requirements: remote or stand-alone and grid connected. Most international applications fall into the remote classification while systems tied to the utility, ranging from residences through central power stations, are considered grid-connected. The design of the remote system is driven by the desired reliability in meeting the load. Energy storage capacity is determined in lifecycle cost tradeoffs with backup energy sources, such as on-site generators. The array is then usually sized to keep the storage charged. Load match is important in the storage sizing but only indirectly affects the array. The allowable costs for remote systems normally makes them nearer-term options, especially important in efforts to industrialize photovoltaic systems. The major concerns in this area are storage costs, state-of-charge sensors and power handling hardware. The last two areas are related to the dispatch of power to the load from the various sources.

System design studies for distributed grid-connected applications indicate that the photovoltaics are best operated in parallel with the utility. In this mode the user buys backup energy from the utility and sells excess energy to the utility. The acceptability of such an arrangement appears to be assured by the Public Utilities Regulatory Policy Act of 1978 (PURPA) which requires utilities to buy energy from co-generators at their avoided costs. While the determination of this "avoided cost" is complex, initial results indicate rates that favor consumer-owned on-site systems. The presence of sellback diminishes the importance of load match in sizing the on-site system. It appears that the fixed costs will be a major factor in residential ($\leq$10kW) systems along with roof area for array placement. Intermediate systems will be influenced by modular subsystem sizing, available array area and initial cost constraints. Energy storage may still play a role in distributed applications but primarily as a user load-leveling device in response to time-of-day utility rates. Such a use is independent of the presence of photovoltaics.

The systems currently favored for residential use tend to be in the 4-8 kW range with size depending on load type and roof area. The lower end is appropriate for meeting just the diversified electrical load where space conditioning requirements are low or met by other sources. For regions with large electrical space condition loads such as air conditioning, the larger sizes are more appropriate. The 8 kW_p maximum results from the extreme architectural design constraints resulting from the need for a large, south-facing roof area. Intermediate systems are normally designed to meet some percentage of the basic electrical load of the applications. Actively-cooled concentrators look especially attractive for uses involving thermal loads such as process heat. In many of these cases the thermal output is nearly as valuable as the electrical output, raising the allowable cost of the system substantially.

At present, the major issue in the distributed system appears to be the utility/customer interface and the requirements placed on the power conditioning unit in the power handling subsystem. The waveform quality and power factor of the energy being fed back into the grid becomes of major importance in interactive systems. There are also questions of stability of the utility grid, safety shutdown considerations, and operational practices which must be addressed before large numbers of sources can be handled reliably.

The photovoltaic central station application is probably the simplest of all systems. Consisting of only an array field and power handling equipment, its primary challenges lie in innovative structure and installation design. Technical issues such as modular field size are being addressed through detailed design and tradeoff activities. These efforts will result in determination of optimum power conditioner type and size, low cost wiring layout and effective installation techniques. Central stations have historically been a long term option in the photovoltaic program, but the rising price of oil may have changed this status. The development of the necessary field test data appears to be one of the major factors in photovoltaic central station commercialization timing.

STAND-ALONE/INTERNATIONAL APPLICATIONS FOR PHOTOVOLTAIC SYSTEMS

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The objective of the Department of Energy Photovoltaics (PV) Program is to develop economically competitive, commercially available photovoltaic power systems that provide safe and reliable energy for four applications sectors.

1. Stand-alone systems for remote applications.

2. Dispersed grid-connected residential systems.

3. Intermediate-sized commercial, institutional, community, and industrial on-site systems.

4. Large-scale central systems.

The PV Program is directed toward the development of photovoltaic power systems which facilitate the timely achievement of the PV Program cost goals. In particular, dispersed grid-connected residential systems are expected to displace significant amounts of centrally generated electricity, first in the Southwest and subsequently, throughout most of the United States. Intermediate sized systems are expected to provide a similar option. Finally, utilities are ultimately expected to augment their generating capacity with larger scale systems. While the utility grid-connected systems are of primary interest as large scale energy displacement options, the remote stand-alone systems do offer an attractive option for special applications remote from grid where systems can be cost effective at a much earlier date, i.e. at higher systems cost.

Photovoltaic systems have the potential to serve larger international commercial markets, serve the needs of developing countries, and ultimately to compete with the grid generated electricity throughout the world. The International Photovoltaic Market can conveniently be considered in three categories: a) the industrialized nations, i.e. the European countries; b) the developing nations with adequate financial resources, i.e. the oil rich countries of the Middle East; and (c) the poorer developing countries. The market in the industrialized nations will likely be limited to remote applications. The market in financially viable developing countries will be energy for their development needs, perhaps providing an alternative to future utility distribution grids. Finally, the poorer developing countries will require energy sources with the assistance of world development institutions, to assure a minimum well-being for their citizens.

Water pumping followed by village power applications are likely to be the markets with the greatest early future opportunity for photovoltaic sales. As photovoltaic prices continue to drop, these markets will become attractive in the early 80's and continue to grow into the future. The pumping market is estimated to be over 100 MWp by 1990 and the village power market is estimated to be 50 MWp by 1990. Satisfying this early market will contribute to the establishment of an industry capable of meeting the ultimate cost goals of the overall program.

Emphasis in the Remote Stand-Alone system development effort has been to field systems with state-of-the-art components to establish candidates for a near term Remote Stand-Alone market. A first generation modular system development is oriented for Agency for International Development (AID) type applications (for the poorer developing nations). A second generation modular system will be oriented more to the larger diesel replacement market.

A number of stand-alone systems have been fielded both domestically and abroad. More are planned under the AID and the FPUP programs. The results of some of those field tests are presented.

The village of Schuchuli is located on the Papago Indian Reservation in Southwest Arizona. The village's 15 families are 17 miles from the nearest utility power. As a consequence the villager's diet has been limited by non-refrigerated food storage, and water has been provided by a diesel powered pump. On December 16, 1978 the world's first Village Photovoltaic Power System was put into operation providing the villagers with electric power for potable water pumping, electric lights, family refrigerators and a communal washing machine and sewing machine.

The Schuchuli Village Power System consists of a 3.5 Kw, 120 volt, DC PV Array, 2380 ampere-hours of battery storage, controls, regulator and instrumentation, and a distribution network. The system is all DC to maximize system efficiency.

The West African Village of Tangaye, Upper Volta, is located about 190 miles east of Ouagadougou, the capital city. The 2700 inhabitants, whose occupations are mostly farming and cattle raising, have to perform a number of labor intensive tasks incidental to those occupations. As a part of a project sponsored by the U.S. Agency for International Development (AID) entitled "Studies for Energy Needs in the Food System" a photovoltaic system powering a grain mill and water pump has been placed in operation on March 1, 1979.

The system consists of a 1.8 KWp, 120 VDC PV Array, 540-Ampere hours of battery storage, regulator, controls, and instrumentation.

Natural Bridges National Monument is located in the high semi-arid country of Southeast Utah. The headquarters area of the 7600-acre Monument has in the past obtained all of its electrical energy from a large diesel-powered generator which operated continuously. A solar PV power system, dedicated June 1980, now relegates the diesel-powered generator to a backup role.

The system consists of a 100 KWp Array, 750 KWh of battery storage, controls, battery charger and inverter. The system provides AC power to the Monument Headquarters.

Experience with installed PV systems, currently powering a variety of services for users in remote areas, confirms that PV systems can provide a viable alternative for energy sources to meet many of the energy needs in remote areas of industrialized countries and the basic energy needs in under-developed countries.

RESIDENTIAL PHOTOVOLTAIC SYSTEMS DESIGN STATUS*

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Residential photovoltaic (PV) system design work was initiated in 1975 with several conceptual design studies. The government sponsored work has progressed steadily from the initial conceptual designs to regional analyses, aimed at identifying the most promising system design in several regions of the country, to detailed system designs, aimed at specifying all the design components and installation requirements for obtaining balance of system costs, to initial prototype system installations at the Residential Experiment Stations (RES). Current work is on-going in the latter two areas and this paper summarizes some of the key design options and design considerations identified.

A residential photovoltaic system consists of three subsystems: the array subsystem, the power processing and control subsystem and the storage subsystem. The simplest system is grid connected with feedback of excess energy to the utility. This system has shown economic viability in practically all regions of the country and will receive the primary emphasis on the first RES system tests.

The design of the PV system has to consider the overall house design, incorporating energy conservation features, passive solar features, energy efficient appliances and an energy efficient HVAC system. Detailed designs developed along these guidelines address component specifications and installation details for several system and subsystem options. Table 1 summarizes the key system design options addressed under contract to Sandia Laboratories. Regional house designs were developed for new construction in the 1986 time frame by Massdesign, Architects and Planners, Inc. of Cambridge, MA. for these system designs. A detailed design report (1) for a Southwest grid connected feedback PV system is an example of the design detail developed.

TABLE 1 - SUBSYSTEM OPTIONS HAVE BEEN ADDRESSED IN EACH OF THE DESIGNS

ARRAY SUBSYSTEM	HVAC SUBSYSTEM
-GE PV Shingle Direct Mount Module	-Heat Pump (HP)
-ARCO Solar Batten Direct Mount Module	-Fossil Heating/Vapor Compression Cooling
-Solarex Stand-Off Mounted Frame Module	-Solar Assisted Heat Pump
-Side-by-Side Flat Plate Thermal Collectors	-Solar Domestic Hot Water (DHW)
	-Space Conditioning Heat Recovery for DHW
STORAGE SUBSYSTEM	**POWER PROCESSING AND CONTROL SUBSYSTEM**
-Feedback Energy to Utility	-Windworks Gemini Inverter
-Lead Acid Battery Storage	-Abacus Sunverter Inverter

This work was supported by the U.S. Department of Energy through programs directed by Sandia National Laboratories, contract number 13-8779.

Combined PV/thermal system options have also been addressed as indicated in the Table. Only side-by-side PV/thermal collectors have been considered since combined flat plate collectors presently require additional development. Utilizing waste heat, recovered from the space conditioning system, for domestic hot water heating was also considered as an alternative to solar thermal energy.

The power processing and control subsystem is centered around the dc/ac inverter. Several units are under development with output quality and initial costs the design tradeoff concerns. The units used in the designs were indicated in Table 1.

The storage subsystem in a grid connected design is primarily a choice of feeding excess energy back to the utility or using on-site storage, with batteries presently being the leading candidate. Incorporating battery storage into the design adds flexibility and delivers more energy to the house load; however, it adds control complexity and increases maintenance requirements. In addition, location of the battery within a residence presents design problems and requires adequate safety design features which also add to system cost.

During the design process, several key considerations were identified. Sizing of the array is one of these key issues. The primary area available for residential PV array is roof area. In grid-connected applications, the system size should be selected to deliver energy to the owner's load at the minimum lifecycle cost, including the cost of backup utility energy. If sellback rates are 50% or greater, study results indicate array areas using all of the available roof area. Incorporating cost effective passive house design features and energy conservation features will reduce the overall household energy requirements and thus reduce the array area requirements. This would allow more flexibility in the architectural house design. Additional background information into system sizing considerations is provided in Reference 2.

The available roof dimensions can further impose constraints on the PV system operating conditions. Rectangular areas are desirable both from an aesthetic viewpoint and from an electrical interconnect standpoint. The roof dimensions, however, limit the number of modules which can be easily connected in a series/parallel network and thus can limit the system operating voltage. The resulting operating voltage can vary on the same roof using different module types. Similarly, the operating voltage may also vary using the same module on roofs with different dimensions. This results in making a common operating voltage range difficult to standardize.

The results of these detailed designs indicate: (1) Grid connected feedback systems have the least complexity and least amount of components, but are dependent on sellback rates to the utility. (2) Solar DHW systems show potential for side-by-side PV/thermal systems, but in areas of high air conditioning loads, the waste heat recovery units show similar energy savings at lower capital costs (3) Location of the battery in a house presents design problems, and the implementation of these systems require adequate safety design features adding to system cost and complexity.

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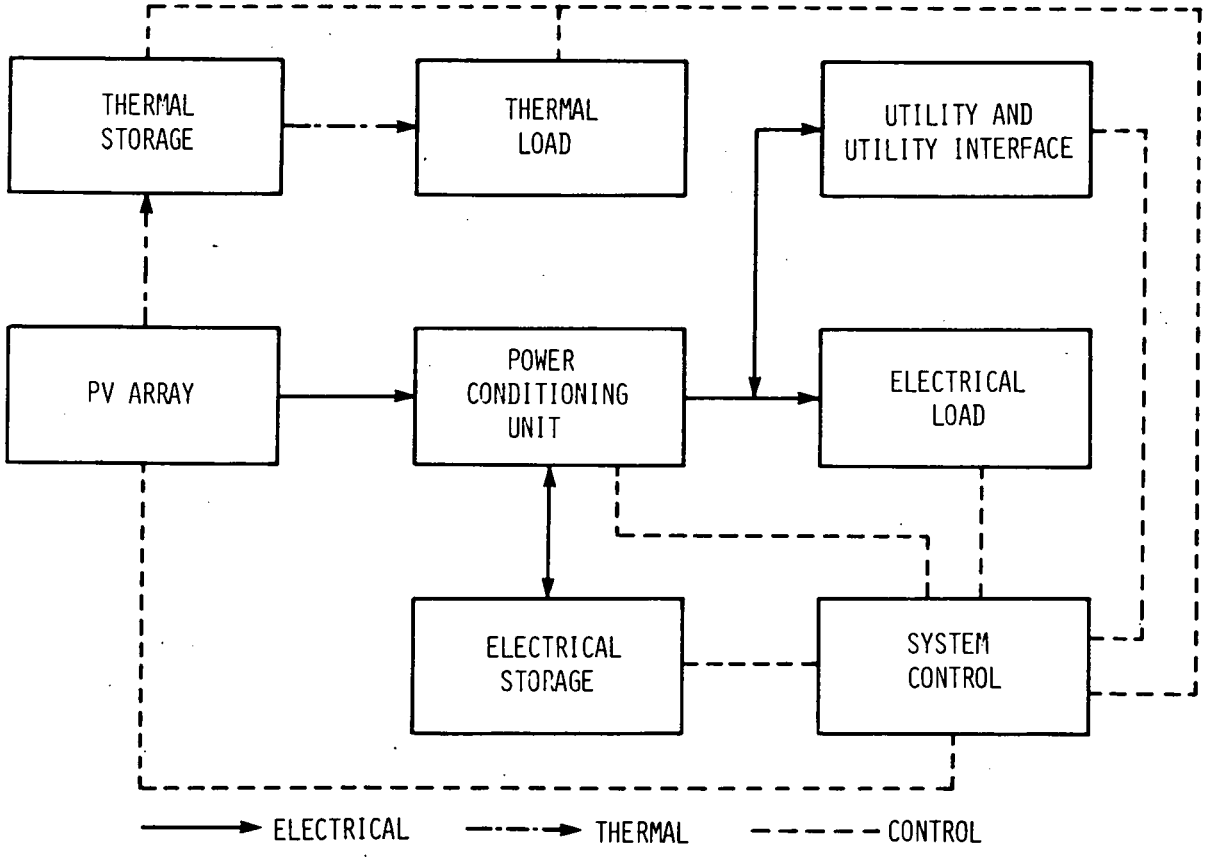
DESIGN OF PHOTOVOLTAIC SYSTEMS FOR INTERMEDIATE APPLICATIONS*

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The first step in photovoltaic (PV) system design is to select subsystems for a conceptual design based on a general knowledge of the application. A general PV system conceptual design would include three or more of the subsystems or components in the block diagram of Fig. 1. The specific application and its loads dictate the choice of subsystems. For example, a stand-alone system would not have a utility interface. Thermal subsystems are required only if the array selected for the system is actively cooled and thermal energy can be used only if there is a thermal load.

After the conceptual design is selected, design options are defined. These might include storage, system size, modes of operation and the use of thermal energy. The next step is to assemble input data used in the optimization routine. These fall into two cate-

Figure 1 A generalized photovoltaic system block diagram. Most photovoltaic systems do not incorporate all of these subsystems or components.



gories: 1) subsystem and component models, and performance characteristics, and 2) input data concerning load demand functions, insolation and weather, and component costs. The weather and load data are usually detailed enough to perform an hour-by-hour system analysis for a typical meteorological year. The design is then analyzed using a computer simulation code and optimization routine such as SOLCEL**. Several other codes have been developed and used successfully in PV system design. The system is optimized by minimizing some objective function such as generated energy cost or lifecycle energy cost. Typical results generated from such an analysis and optimization are component rating and sizing, array circuit and field layout, control requirements, and system performance. Finally, the final system design is specified.

The system optimization fixes the performance and requirements of the various components and subsystems. The presentation will illustrate the design methodology using examples of detailed designs from the current DOE application experiments program. Although techniques for designing PV systems are well established, they are just now beginning to be verified experimently through the applications experiment program. Initial indications are that the methodology is sound.

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**E. R. Hoover, SAND79-1785, Sandia National Laboratories, Albuquerque, NM, Feb. 1980.

PHOTOVOLTAIC SYSTEMS FOR CENTRAL POWER APPLICATIONS

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It is clear that the central power application represents the largest of all the potential markets for photovoltaic solar energy conversion -- and therefore the most important from the point of view of contributing to the solution of the national energy problem. Because this application has, until recently, been viewed as a relatively far-term one, however, there has been less urgency in the National Photovoltaic Program about developing detailed system designs for it than for the residential and intermediate-load-center applications, and no central power experiments have yet been launched. There is, therefore, somewhat less solid information about the details of central station design than about the designs for the smaller systems, but their general characteristics have been fairly well defined by a sequence of conceptual design studies (Refs. 1-6).

The most important difference between a photovoltaic central power plant and the photovoltaic systems that are used for the other applications is that the central power plant will be enormously larger -- hundreds of times larger than any system yet built. Utility sources suggest that such a plant should have a generation capacity of 50-500 MW; the land area required will therefore amount to hundreds, or even thousands, of acres per plant.

It is also clear that these plants will be highly modular. The large field of collectors (whether flat-plate or concentrator) will be divided into subfields, each with its own power conditioning unit (to convert the DC array output to 60 Hz AC and transform it up to the desired in-plant AC bus voltage), together with the necessary control circuitry and AC and DC switchgear. The power from these subfields will probably then be combined at an output transformer that will raise the AC voltage to the required magnitude for transmission into the grid. Because of their modularity, commercial photovoltaic power plants will probably be constructed in stages, and each stage will go on line, producing its increment of power, as soon as it is completed. The resulting flexibility in scheduling the addition of photovoltaic capacity is a particularly attractive feature.

Since the collectors in a photovoltaic central power plant will be mounted solidly on the ground, rather than on the roof of a building, there are essentially no limitations on the size and weight of an individual collector unit. All types of concentrating collectors may therefore be considered in the design of a plant, with concentration ratios ranging from unity to many thousands. The optimal choice will depend on the resulting cost and performance of the total system. An expensive concentrating collector that has high conversion efficiency may lead to lower overall energy costs (because of reductions in the required area of collector and in the required amount of support structure and DC cabling) than would a low-cost collector of lower efficiency.

There are, in addition, a number of other trade-offs that must be evaluated in order to optimize a photovoltaic power plant design. For example, the size and DC voltage rating of the collector subfield will determine the power and DC voltage ratings of the power conditioning unit, and the optimal values for these parameters will depend on a complex set of trade-offs. Increasing subfield size (and power conditioner rating) leads to increased DC cable lengths and greater power losses unless heavier (and more expensive) conductors are used or unless an increment of collector area is added to compensate for the increased resistive loss. Also, although higher DC voltages reduce ohmic losses and permit the use of lighter and cheaper conductors, they also lead to a requirement for better-insulated (more expensive) collector modules and switchgear.

These and other critical design issues are currently being examined; although the complete results of these efforts are not expected to be available by the date of the conference, preliminary results will be reported.

The development of preferred designs for photovoltaic central power plants has thus lagged, to a degree, behind the systems definition work for the lower-power applications. This situation is now changing rapidly, however. The rapid rise in oil prices, coupled with the steady progress of the National Photovoltaic Program toward its collector price goals, has given rise to the prospect that photovoltaic central power plants may well be economically competitive in some locations by the late 1980s. As a result, the relative priority of the central power application in the Program has risen, and plans for the development of detailed system designs and for the fielding of a first central station experiment have been accelerated.

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PHOTOVOLTAIC BALANCE OF SYSTEM DEVELOPMENT STATUS

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The majority of photovoltaic power supplies require foundations, support structures and wiring, as well as other facilities and/or equipment to integrate the photovoltaic collectors into a functioning power system. These equipment and facilities are commonly referred to as the balance of system (BOS). For purposes of establishing cost goals and evaluating system designs, the United States Department of Energy (DOE) considers BOS costs to include costs for materials, installation, system design engineering and other indirect costs, for all elements other than the collectors. As the DOE cost goals for collectors (e.g., $0.70/peak watt in 1980 dollars by 1986) are achieved, optimization of BOS designs and development of low cost BOS equipment will be essential to ensure that photovoltaic power systems will be economically viable over the broad range of potential terrestrial applications. Consistent with present DOE practice, all costs reported herein are presented in terms of constant 1980 dollars.

BOS design is dependent on array type, system size, system location, load characteristics and other application specific factors. BOS requirements generally include array support structures and foundations, wiring, power conditioning equipment and controls. The system may also include energy storage and/or an interface to a non-solar backup power supply such as the local utility or an on-site diesel generator.

BOS components can be broadly grouped into two categories: 1) power related components, such as power conditioning and energy storage equipment, and 2) area related components, such as foundations, support structures and wiring. The principal distinction, in terms of system cost impact, is that the power related costs are primarily influenced by system size (i.e., the requirements of the load), while the area related costs are affected by both system size and collector efficiency. Specifically, the quantity of support structure, wiring and other area related BOS components required per peak watt of system output increases with decreasing collector efficiency. Therefore, a trade-off exists between collector cost, collector efficiency and area related BOS costs. It is appropriate to discuss the costs of power related BOS components in terms of $\$/W_p$, while area related BOS costs are more useful when presented in terms of $\$/m^2$ of collector area.

Present BOS costs, for installations having peak power ratings on the order of several kilowatts, are generally within a range of about 10-20 $\$/W_p$. BOS costs for the nine Program Research and Development Announcement (PRDA) experiments, having power levels ranging from 17.5 kW_p to 225 kW_p, selected by DOE for continuation into the construction and operational phases also appear to be in this range. However, these systems generally represent one of a kind designs and the BOS costs likely include additional costs resulting from component development, low volume equipment manufacturing and similar factors.

The DOE BOS cost goals for the various application categories and commercial readiness time-frames are summarized in Table 1.

The remainder of this discussion summarizes the present status and development trends of the major BOS elements, including: 1) support structures and foundations, 2) power conditioning equipment, and 3) energy storage.

TABLE 1 BALANCE OF SYSTEM COST GOALS (1980 DOLLARS)

Application	Year	Cost ($/W$_p$)
Mid-term markets	1982	3.20-10.20
Residential	1986	0.90-1.50
Intermediate	1986	0.90-1.90
Central Station	1990	0.70-1.65

Support/structure foundation design requirements, and therefore costs, are dependent on application specific factors and the type of collector used. For example, a residential system using integrally-mounted shingle type modules may not require any additional support structure and might even claim a credit for the conventional shingles they replace. On the other hand, ground-mounted flat plate modules (or those mounted on flat roofs) require special foundations and/or support structures. For concentrating arrays, some or all of the support structure may be provided by the tracking and concentrating mechanisms, tending to blur the distinction between collector costs and BOS costs. A major factor affecting support structure/foundation design and cost is the expected load magnitude resulting from wind, snow and other ambient conditions. At present, the effects of wind loading on support structures located within an array field are not well defined. It is hoped that the results of wind tunnel testing and other ongoing studies will provide the rationale for relaxing the somewhat conservative assumptions being used at this time. Present support structure/foundation cost estimates, based on studies conducted by Bechtel and others, range from about 15 to 40 $/m^2 of collector area (1 m^2 of collector produces 100W at 1 kW/m^2 insolation and 10 percent efficiency). These designs tend to be somewhat material and labor intensive. Future cost reductions in this area will require both innovative design and use of labor saving installation techniques.

Requirements for power conditioning equipment can range from a simple dc voltage regulator to sophisticated inversion systems capable of transforming the dc array output to ac power compatible with the local utility system. Similar equipment is commercially available and is used in diverse applications including variable speed motor drives and battery powered emergency power supplies. Inversion equipment is also being developed for use with fuel cells, utility load leveling batteries and other dc power sources, as well as to meet the specific needs of photovoltaic power systems. Cost estimates for dc to ac power conditioning equipment vary considerably with size, production quantity, technology (e.g., self-commutated versus line-commutated) and manufacturer. In many applications the power conditioning equipment must, in addition to accomplishing the dc to ac inversion, include additional equipment such as harmonic filters and power factor correction capacitors to provide ac power of the required quality. If required, it is important to ascertain whether the cost of this additional equipment is included in the "inverter" cost estimate. Cost estimates for commercial production volume units are in the range of about 0.15 to 0.25 $/$W_p$ for residential (e.g., 10 kW) sized units and about 0.05 to 0.10 $/$W_p$ for large (e.g., 5 MW_p) sized units.

In some photovoltaic applications it is desirable to include on-site energy storage. At present, lead-acid and, in some cases, pocket plate nickel-cadmium batteries are the only viable storage mediums. Present costs of suitable lead-acid batteries range from about 100 to 200 $/kWh (0.30 to 0.60 $/$W_p$ for 3 hours of storage). Improved lead-acid and other advanced battery types are presently under development for electric vehicle and utility load leveling, as well as solar power applications. Current projections indicate that these batteries may have costs in the range of 50 to 100 $/kWh (0.15 to 0.30 $/$W_p$). Other storage mediums, such as flywheels, are also being considered.

RESIDENTIAL TESTS AND APPLICATIONS *

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The first residential photovoltaic systems built for the U. S. Department of Energy's (DOE) Solar Photovoltaic Residential Project will be designed and fabricated during 1980. These systems will be tested at the Northeast Residential Experiment Station in Concord, Massachusetts. Soon after, systems designed for the Southwest will become operational at the Southwest Residential Experiment Station in Las Cruces, New Mexico. In addition to the systems at the Residential Experiment Stations, DOE is supporting a small number of independent residential system development efforts where unique circumstances promise early acceptance of photovoltaics.

The goal of the DOE residential project is to develop residential photovoltaic systems which will be sold for $1.60 per watt peak by 1986 (in 1980 $s). To manage the development of such systems, the DOE is establishing regional Residential Experiment Stations in the northeastern, southwestern and southeastern United States. System hardware development at each Experiment Station will involve two phases. First, Prototype Systems will be installed on the station grounds. These are residential roof structures on which are installed photovoltaic collectors and in which are housed DC-to-AC power-conditioning equipment. Unoccupied structures first used to test fully integrated photovoltaic collector and power-conditioning systems, these will be highly instrumented and provide detailed engineering performance and reliability data. The second phase will follow the successful operation of a Prototype System and will entail installing a refined version of the same system on a house in the community surrounding the Experiment Station. Called Initial System Evaluation Experiments, these will be used to assess occupant acceptance and reaction to residential photovoltaic systems.

Five Prototype Systems are currently being designed for testing and evaluation at the Northeast Residential Experiment Station: four under turnkey system procurement contracts, the fifth by Lincoln Laboratory. All the systems will use simple photovoltaic modules and exchange energy with an electric utility grid.

The Lincoln Laboratory system will use 120 Solarex Semix modules and will be rated at 6.9 kilowatts peak at standard operating conditions. The array will be 21 by 48 feet and mounted directly above a 22- by 52-foot roof. An innovative aspect of the mounting technique is that the modules will be attached to the roof with rollers and tracks. Based on standard garage-door mounting hardware, this method will facilitate installation and servicing of the modules.

The characteristics of the four turnkey residential Prototype System contracts are compared to those of the Lincoln Laboratory-designed system in Table 1. The four designs include examples of three types of module mounting: standoff, which supports

*This work was sponsored by the U. S. Department of Energy. The U.S. Government assumes no responsibility for the work presented. DOE/ET/20279-104

the modules above the roof weather-seal; direct, which places the module on the roof sheathing; and integral, which substitutes the module for all roofing materials above the rafters.

Table 1
NORTHEAST RESIDENTIAL PHOTOVOLTAIC SYSTEM CHARACTERISTICS

System Designer	Array				Power Conditioning
	Size	Power	Density	Tilt	Size
Lincoln Laboratory	93.7 m^2	6.9 kW	73.6W/m^2	45°	8 kVA
General Electric	73.3	6.1	83.4	33.7°	6
Solarex	74.3	6.2	83.3	40°	6
Tri-Solar Corp.	47.6	4.8	101.0	45°	8
Westinghouse	59.5	5.4	91.5	45°	6

On a schedule closely following the Lincoln Laboratory-designed Prototype System, a similar system will be installed in a house to be built in Carlisle, Massachusetts. While the photovoltaic array may be somewhat smaller, the same mounting technique and an identical power conditioner will be utilized. A primary objective of this project is to familiarize local builders, developers and town building officials with photovoltaic systems prior to the fielding of commercially designed systems which will evolve from the present set of turnkey Prototype Systems.

The focus of residential activity in the southwestern United States is the Southwest Residential Experiment Station, located in Las Cruces, New Mexico, and operated for DOE by the New Mexico Solar Energy Institute. During the summer of 1980, proposals for southwestern Prototype Systems will be solicited. Though similar in design to the systems used in the Northeast, the southwestern systems will be adapted to southwestern architectural styles, the photovoltaic arrays will be designed to better reject unwanted thermal energy, and the roof slopes will be reduced to reflect the roughly 10° difference in latitude.

Three independent projects are under way. With cost sharing from the DOE, the Florida Solar Energy Center has built a photovoltaic system on a prebuilt 1300-square-foot home. The array is made from 140 Arco Solar type 16-2000 modules and is rated at 4.2 kilowatts at standard operating conditions. John F. Long Properties, Inc., a Phoenix homebuilder, is teamed with Arco Solar, Arizona State University and the Salt River Project (electric utility) to build and test an experimental residence. The array is made from Arco Solar batten-seam modules and is rated at approximately 5.7 kilowatts. The Hawaii Natural Energy Institute has also teamed with Arco Solar to build three residential systems: two in Honolulu and one on Molokai. One Honolulu system and the Molokai system will involve retrofit 2-kilowatt-peak and 4-kilowatt-peak arrays, respectively. The second Honolulu system will involve new construction and a batten-seam module array rated at 4 kilowatts. The dependence of Hawaii on oil for all of its electric power results in high electric prices. Combined with insolation equal to that of the Southwest, this factor may make Hawaii the first large U. S. market for residential photovoltaic systems.

INTERMEDIATE SECTOR PHOTOVOLTAIC SYSTEM TESTS AND APPLICATIONS*

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The Tests and Applications (T&A) subprogram of the National Photovoltaic Program has been designed to address four potential application market sectors: (1) remote, (2) residential, (3) intermediate, and (4) central station. Remote applications are those which are not interconnected to the utility grid, either because the grid is remote or the system was designed to stand alone for a variety of reasons. The other three application sectors use grid-connected systems. The intermediate sector is defined as other than single-family detached dwellings and utility-owned or -controlled substations or central stations. This primarily includes on-site service, commercial, institutional, and industrial applications where the photovoltaic (PV) systems are owned by the site owner.

The intermediate sector T&A subprogram has emphasized, in its initial stages, the design and installation of PV systems in several of the most promising on-site applications. These are referred to as initial system evaluation experiments (ISEEs) since they represent the first of a kind and are designed to provide system-level experience which assists in evaluating the potential worth of a PV system in a particular application. To date, twelve ISEEs are in various stages of design and installation. These are listed in Table I along with summary information about each project.

Table I Ongoing Intermediate Photovoltaic Application Experiments

Application	Location	Size (kWp)	Array Technology	Initial Operation
Airport	Dallas, TX	30	Concentrator	6/81
Airport	Phoenix, AZ	225	Concentrator	8/81
Amuse. Park	Orlando, FL	110	Concentrator	11/81
Hospital	Kauai, HI	60	Concentrator	4/81
Light Mfg.	San Bernardino, CA	35	Flat Plate	7/81
Museum	Okla. City, OK	150	Flat Plate	1/81
Office	Albuquerque, NM	50	Concentrator	12/80
School	Beverly, MA	150	Flat Plate	1/81
School	Blytheville, AR	240	Concentrator	10/80
School	Senathobia, MS	150-200	Concentrator	10/80
Shopping Ctr.	Lovington, NM	150	Flat Plate	1/81
UPS	El Paso, TX	20	Flat Plate	11/80

As these systems become operational a two-year operational phase will be initiated to operate and evaluate system performance. The data, which will include array dc output, dc-to-ac inverter output, load requirements, and weather data, will be assembled, reduced, and analyzed at a central data reduction center. Monthly, quarterly, and annual reports will be widely distributed to appropriate data users. In addition raw data, in the form of magnetic tapes, will be made available to the user who desires to perform his own more detailed analysis and evaluation of system performance.

The results of these initial experiments will be used to design the next generation of experiments. Also the results will provide feedback into technology development programs to insure a more appropriate component for eventual commercialization of PV systems in the intermediate market sector.

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CENTRAL STATION TESTS AND APPLICATIONS

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Of the many potentially attractive applications for photovoltaic solar energy conversion, the one capable of making the greatest long-run contribution to the U.S. energy supply is the application to central station (utility) power generation. This application has, however, generally been viewed as only a far-term possibility for photovoltaic technology, primarily on the basis of analyses that have shown that photovoltaic system costs would have to be reduced to the \$1.10-1.30/W_p (1980 dollars) range -- corresponding to collector module prices of \$0.15-0.40/W_p -- in order to be competitive in the central station market. Although intensive development of the currently-available silicon-based collector technologies (the "baseline technologies") is expected to lead to module prices of \$0.70/W_p by 1986, significantly lower prices will probably not be achievable in this way. New and more advanced collector technologies now under development are expected to yield \$0.15-0.40/W_p module prices, but not until the 1990's. Consequently, photovoltaic central station power plants have not been expected to become economically competitive much before the end of the century, and the early planning of the National Photovoltaic Program reflected this perception.

In the period since these analyses were carried out, however, there have been substantial changes in the competitive situation for photovoltaic power in at least some parts of the utility industry. The most striking event, of course, has been the rapid and continuing increase in the price of fuel for oil-steam plants. As a result of these very large increases in oil prices, it now appears that it would be cost-effective in some U.S. utility systems to construct baseline-technology (\$0.70/W_p collectors) photovoltaic power plants solely for the purpose of saving oil. In Fig. 1 the breakeven cost of a photovoltaic plant under these conditions is plotted as a function of the first-year cost of oil (in 1980 dollars). The breakeven value of the total installed cost of a photovoltaic power plant was determined by equating the levelized annual cost of owning and operating the plant with the levelized annual cost of the oil displaced. The oil price was assumed to remain constant in real terms (i.e. to rise exactly

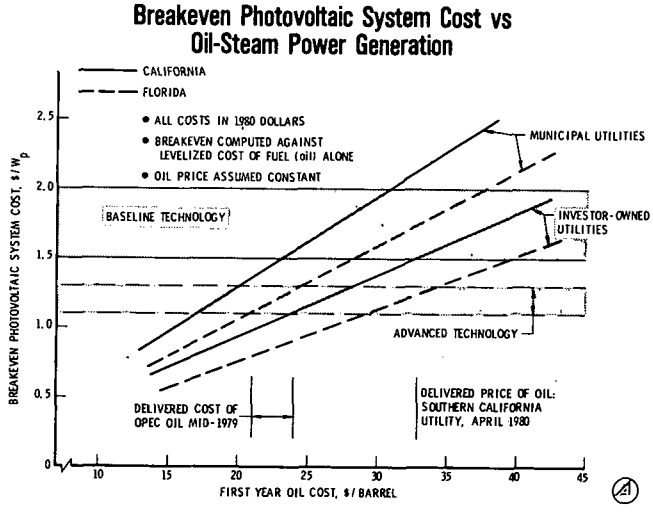


Fig. 1 Breakeven Photovoltaic System Cost vs. Oil-Steam Power Generation

at the rate of general inflation). The solid lines represent photovoltaic plants in a desert site in Southern California or Arizona, while the dashed lines correspond to a location having the sunshine characteristics of Miami, Florida.

This figure shows that, for oil prices in the $30-35/barrel range, photovoltaic plants using baseline technology (and costing $1.50-2.00/$W_p$) would be cost-effective in municipal utilities (with their lower cost of capital) in either the Florida or the California location. When the price of oil approaches $40/barrel (still in 1980 dollars), such plants will be cost-effective oil-savers even in investor-owned utilities. In fact, since the cost of oil to some California utilities is already more than $30/barrel, it would be economically reasonable to construct a photovoltaic plant right now, if construction costs in the vicinity of $2/$W_p$ had already been demonstrated.

It thus appears that, by the mid-to-late 1980's, the construction of baseline-technology photovoltaic power plants may well be a viable option for Sunbelt utility systems, especially municipal systems, that are heavily dependent on oil-fired generation. These considerations have led to the adoption of a two-part strategy in the recent planning of the central station portion of the National Photovoltaic Program. The first part involves the use of the baseline collector technologies in a program aimed at $1.50-2.00/$W_p$ system costs. The objective is early penetration of the utility market with photovoltaic plants that are constructed to save oil in favorably-located utilities that are heavy users of oil. One or more central station experiments (in the (1-2 MW size range) are now being planned, with probable construction dates in the 1983-84 period.

The second part of the central station strategy will be targetted on the broader utility market through the development of systems that could be built, given sufficient construction volume, for $1.10-1.30/$W_p$. These systems would use one or more of the advanced collector technologies that are now under development and expected to be technology-ready by about 1986. System-level experiments using such collector technologies are planned for the 1987-1988 period.

INNOVATIVE TESTS & APPLICATIONS OF RESIDENTIAL PHOTOVOLTAIC SYSTEMS

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After having completed many custom single family residences which rely on renewable energy for heating, cooling and hot water; our quest to design an energy self-sufficient living environment led us to consider the various options available to produce electricity on a household scale using renewable energy.

Solar photovoltaic power systems were especially intriguing to us because they are not nearly as site dependent as other technologies; they generate electricity whenever the sun shines with no moving parts and virtually no maintenance, and most important, they can be integrated with the building as a working part of the architecture, advancing us yet another step closer to the ideal design metaphor of the building as an energy producing organism.

The houses described here represent two different approaches to residential P.V. systems development. One is a prototype residence designed for the Northeastern U.S. employing a high density roof integrated P.V. array, and the other is a custom designed earth-sheltered residence featuring a high efficiency roof integrated combined photovoltaic/thermal energy system of advanced design.

As a result of a competitive DOE solicitation, Solar Design Associates was awarded a contract for the design of a prototype photovoltaic residence for the Northeastern United States. This program included the design of a passive, energy conserving residence configured to accept a nominal 5 Kwp P.V. system, and the construction and integration of a prototype of this P.V. system for testing and evaluation.

This photovoltaic residence was designed to be marketed in the 1984-1986 time frame by a custom builder to satisfy the requirements of a family of four and sell in the upper middle segment of the housing market. The design is contemporary, but not outlandish- chosen to appeal to the wide variety of tastes which compromise the speculative housing market. The size is approximately 170 M^2 of net living area.

State-of-the-art energy conservation and passive solar techniques were employed and the south roof was designed to present an area of 48 square meters, in one plane, facing due solar south and inclined at 45° for the P.V. array.

We felt that a roof area any larger than 50 sq. M. devoted to a solar array on a 170 M^2 house would simply be too much of a dominant monolith for the house design to accept gracefully. Using high quality square single crystal silicon solar cells with a conversion efficiency of 13.5%, we were able to design a P.V. module with an overall module efficiency of 12.5% to satisfy our power output requirements with a minimum array area.

The P.V. modules are a glass superstrate design using .47 cm thick tectured and tempered A.F.G. Sunadex glass. The cells are 6.426 cm square, cut from 7.62 cm round wafers. Each module has 23 cells in series by 11 in parallel and measures 79 cm wide by 162.5 cm high overall. The module's peak electrical power output is 133

watts (under 1000 W/M^2 at 28^oC).

The P.V. modules will be mounted directly over the roof rafters to form a water tight weather seal, replacing the roof shingles, plywood and other materials required for a conventional roof, and allowing access to the P.V. modules from behind for wiring, inspection, and maintenance.

Our prototype P.V. array consists of 36 of these modules wired 18 in series by 2 in paralell, resulting in a peak power output of 4.785 Kw at 202.5 V and 23.62 A (under 1000 W/M^2 at 28^oC). The projected output for this array in Boston is a net average of 18.32 Kwh/Day which makes our photovoltaic residence a net exporter of electricity if the diversified electrical load is in fact reduced to 16 Kwh/Day as we feel it will be.

The second residential application of P.V. is a custom designed private residence near Boston, Ma. where the stated goal was to produce as nearly a self-sufficient living environment as possible.

Our response was to design a compact earth sheltered house using masonry and steel construction for thermal mass, with full south glass for direct passive solar gain, and super insulation and earth covering on the roof and north, east and west walls for energy conservation and temperature stability. We included a solar greenhouse and planned a large garden plot for food production, and installed a Clivus Multrum for waste recycling to complete the cycle.

To provide the electricity and thermal energy for this residence, we decided to design a combined photovoltaic / thermal energy system to satisfy both requirements from the same solar array. To fund the engineering development work necessary for the design of a high efficiency PV/T collector, we submitted an unsolicited cost sharing proposal to DOE.

Our proposal was accepted and we began our work with a comprehensive assessment of all of the parameters affecting the design and integration of the combined P.V./T systems. We investigated basic collector configurations, the use of air and liquid as heat transfer media, cell configuration and efficiencies, cell bonding and encapsulation, glazing systems and architectural integration.

As a result of this assessment, we decided to use a liquid cooled flat plate configuration with high density P.V. modules employing rectangular cells for our P.V./T system design. This conclusion was arrived at for the following reasons. First, supporting structure for solar collector arrays is very expensive. This is especially true if the supporting structure is a house. To keep construction costs as low as possible and to minimize the architectural impact of an array of P.V./T collectors on the house, it is important to obtain the maximum electrical output per net square meter of collector area. Second, in a well designed home which is built in keeping with today's energy conservation practices, the combined thermal energy loads of space and domestic hot water heating can be satisfied with a modest solar thermal collector array.

Our initial performance simulations indicate our flat plate design produces a ratio of thermal energy to electrical energy nearly ideal for residential applications. We have built two prototypes of our P.V./T collector which are currently undergoing extensive testing and evaluation. If the results of these tests confirm our engineering calculations, we expect to fabricate and install a 6 kilowatt (peak) P.V./T array on the Milton house early in the spring of 1981.

REVIEW OF STAND-ALONE PHOTOVOLTAIC APPLICATION PROJECTS SPONSORED BY U.S. DOE AND U.S. AID

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The NASA LeRC manages two projects involving the deployment of small-scale, decentralized photovoltaic (PV) power systems for rural or remote areas of the world. For the U.S. Department of Energy (DOE), LeRC manages the Stand-Alone Applications Project which is part of the National PV Program. The objective of this project is to accelerate the commercialization of PV through the stimulation of the latent worldwide market by means of cost-shared demonstration projects. For the U.S. Agency for International Development (AID), LeRC manages the PV Development and Support Project, the objective of which is to determine the suitability (i.e., reliability and cost-competitiveness) of PV power systems for development assistance activities in rural areas of developing countries.

While different in terms of program objectives, the DOE and AID activities are similar in demonstrating the applicability of photovoltaics to a variety of users and are complementary in that AID, as a user, specifies the needs and requirements to be met by PV systems in support of development assistance activities while the DOE program also provides the requisite technology to meet those needs. LeRC, as technical manager for both projects, coordinates to assure the appropriate interaction, facilitate technology transfer and prevent duplication of effort.

Under the DOE Project, LeRC has deployed some 20 systems, mostly single function experiments such as communication or refrigeration, ranging from Hawaii to Maine and from Alaska to the Florida Keys. The most significant experiment to date, however, is the world's first village PV power system in the Papago Indian Village of Schuchuli, Arizona. This 3.5kW peak, 120 volt DC system, which became operational on December 16, 1978, provides the 95 villagers with electrical power for potable water pumping (for domestic use and livestock), lights in the homes and community buildings, family refrigerators, a communal washing machine and a sewing machine. The system to date has performed continuously except for several brief outages caused by control system malfunctions which have been subsequently corrected. Another significant multi-function experiment deployed by LeRC involves two fire lookout towers in northern California operated by the U.S. Forest Service. The 294 watt peak PV systems at these sites each power a water pump, refrigerator, lights and a 2-way radio. Both systems have been operating satisfactorily since they became operational in October of 1976.

Under U.S. AID sponsorship, a PV system powering a grain mill and a water pump was installed, under LeRC management, in the West Africa village of Tangaye, Upper Volta and became operational on March 1, 1979. The 1.8kWp, 120V DC system supplies DC electrical power to a grain grinder and a water pump. A cooperative has been formed by the villagers of Tangaye to manage the mill. About 60 village families invested in the enterprise. Charges for milling are set by the cooperative and are competitive with commercial mills in the region. Proceeds from membership and milling are used to pay two full-time millers and to accumulate funds for spare parts and repairs. Additional profits are distributed to cooperative members. The water pump provides up to 15,000 liters of water per day for domestic and stock use. The water is available to all villagers free of charge.

As part of LeRC's management responsibility for DOE for all international PV applications, exclusive of the so-called "bilateral agreement" projects, additional PV systems will be installed overseas to stimulate market development. For example, "community service" PV packages will be installed in four different villages in Gabon as part of a joint cost-shared demonstration project with the government of Gabon. Under contract to U.S. industry, primary market studies have been and are being performed relative to three application categories, viz., village power, agriculture and cottage industry in support of the overseas commercialization efforts.

For AID, PV wind and solar heating units will be installed in the village of Hammam Biadha in early 1982 as part of the LeRC-managed Tunisia Renewable Energy Project. In addition, a series of PV pilot tests will be deployed at rural health centers in Guyana, Kenya and several other countries in 1982.

As part of an activity involving both DOE and AID, PV-powered refrigerators for cold chain preservation of vaccines will be field tested at 18 sites around the world, 8 for DOE in conjunction with the Center for Disease Control and 10 for AID. The first refrigerator experiments will become operational in late 1981.

An analysis of the cost of energy derived from PV systems at remote sites indicates cost-competitiveness relative to diesel generators at today's PV module prices for cases where diesel fuel cost (delivered) is $3/gal. Figure 1 illustrates the cost of diesel-generated electricity for selected power profiles and levels of energy consumption. Assumptions are noted in the legend. Note that PV energy costs today are competitive at levels below 6000kWh/yr and below about 20,000kWh/yr by 1986.

A similar comparative analysis involving the extension of utility lines indicates that PV systems are competitive at today's prices with utility line extensions of 16 km (10 miles) or more, again for electrical energy consumption of about 6000kWh/yr or less. This "break even" level of energy consumption is projected to extend to 20,000kWh/yr or more by 1986.

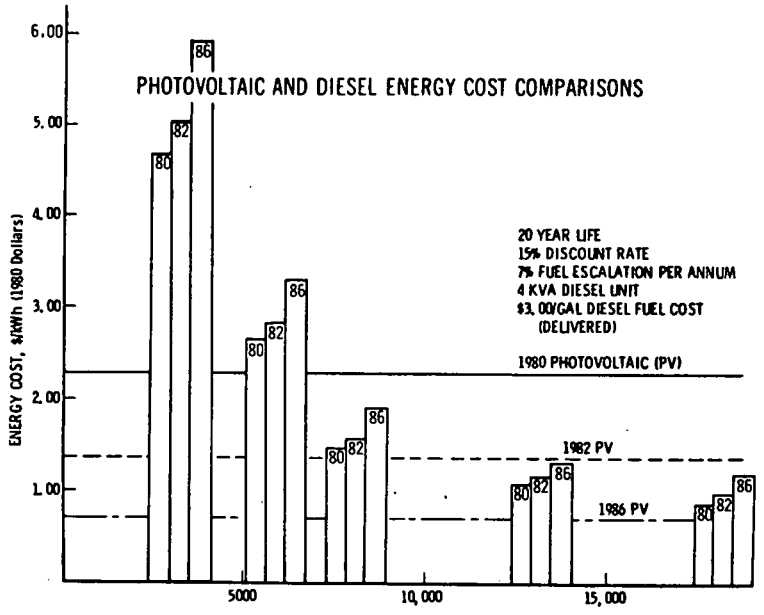


FIGURE 1. - ANNUAL ELECTRICAL ENERGY CONSUMPTION, kWh/YR

Dup

THE PHOTOVOLTAIC POWER SYSTEM AT NATURAL BRIDGES NATIONAL MONUMENT*

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The 100-kWp photovoltaic (PV) power system implemented by MIT Lincoln Laboratory under U.S. Department of Energy sponsorship serves a small self-sufficient community, isolated from the utility grid, at the Natural Bridges National Monument (NBNM) in southeastern Utah. This power system is providing information important to the successful operation of future systems: namely, data leading to improved models for system sizing and design as well as reliability, maintenance and performance data on critical PV system components. The park is visited by over 80,000 people per year and thus offers an excellent opportunity to educate the public on renewable energy sources and energy usage. The PV system is operated by the park staff.

Figure 1 shows a block diagram of the system which has been in operation since May 1980. The 100-kWp array area is located approximately 1200 feet south of the PV equipment building on an inconspicuous south-facing hillside. The flat-plate, glass-covered modules are mounted in twelve rows, each containing eight 8 X 24-foot frames. Although the tilt angles can be adjusted, the frames are set at a fixed 40° tilt to favor the winter season and to facilitate snow shedding. Power is transmitted to the PV building with buried cables from each of the 48 subarrays.

Automatic control for the system is implemented with a microprocessor which is primarily used to monitor and manage the battery state of charge. Control of battery charging current and voltage is implemented by shedding subarrays with mercury-relay switches. The controller also monitors battery state of charge by integrating the battery current and starts the backup diesel-powered generator and battery charger if the state of charge reaches a predefined lower limit or if periodic battery equalization is required.

The system incorporates electrical storage since it must provide power 24 hours per day and is not served by a utility grid. Thus this system will provide operational experience with a large lead-acid storage battery (600 kWhrs 3520 Ah) pertinent to the design of future systems incorporating storage for load leveling or stand-alone requirements. The battery uses a calcium additive in the lead plates to minimize the production of hydrogen gas during charging; its cells are also equipped with catalytic recombiners to further reduce the explosion hazard. These measures also limit water loss and therefore reduce maintenance. The battery is sized to provide about two days of storage in cloudy weather.

Two inverters are used in the system. The first is a 5-kVA uninterruptible power source (UPS) inverter used to isolate the control system from load-induced voltage variations on the main inverter. The main inverter, with a capacity of 50 kVA, is several times larger than the average site load in order to provide adequate starting current for large (2-3 HP) AC motors.

*This work was sponsored by the U. S. Department of Energy. The U. S. Government assumes no responsibility for the work presented. DOE/ET/20279-105

During the initial checkout of the system, four inverter-related problems were encountered: 1) overload of the main inverter at turnon due to initial core saturation in a large power distribution transformer, 2) radio noise emanating from the main inverter, 3) sensitivity of the inverter control circuitry to radio frequency (450 MHz) energy from a nearby radiotelephone, and 4) malfunction of the small UPS inverter resulting from the very low resistive source impedance in the large battery. These problems were solved with: 1) a resistive starter to limit initial current, 2) power-line filtering, 3) RF filtering, and 4) a small series resistor.

In designing the system, considerable effort was expended to reduce overhead loads and to meet the year-round energy needs with a minimum of diesel-powered generator operation. As a consequence, the average site AC load, including PV overhead, is about 12-17 kW. The PV building requires approximately 1 kW for fans and evaporative coolers in the summer season. In winter, waste heat from the inverter is circulated to heat the building and the corresponding load is less. In addition, the UPS AC load is about 800 watts year-round. Averaged over a year, the backup generator is projected to supply less than 15% of the total energy consumption.

In Fig. 2 the estimated load power profile, at the DC bus assuming constant 24-hour demand, is shown based on 1979 actual load data adjusted for inverter losses and overhead loads. This load is artificially high, due to the previous practice of base loading the generator with extra lights and winter season heaters for proper diesel load. Also shown is the maximum available array power, which is what might be collected if a maximum-power-point tracker were used to extract the full output from the array. This is, of course, an upper bound on the available energy. A more realistic profile is shown by the expected collectable power which estimates what this system can supply during the year. With these load estimates, a net energy deficiency during December and January will have to be made up by diesel operation. With conservation measures in effect, the projected deficits in the winter season will be less than is suggested by Fig. 2.

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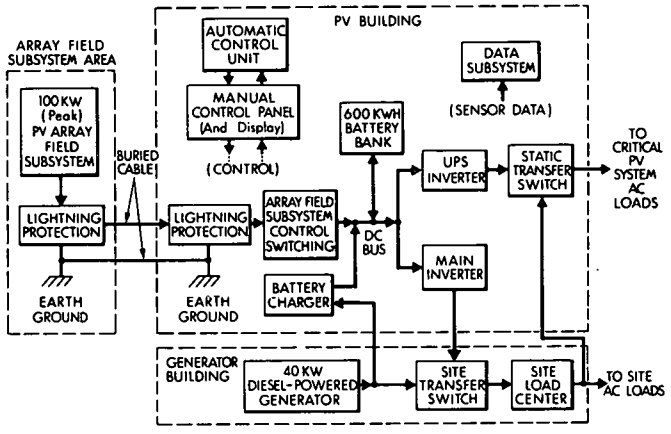


Fig. 1. Simplified PV power system.

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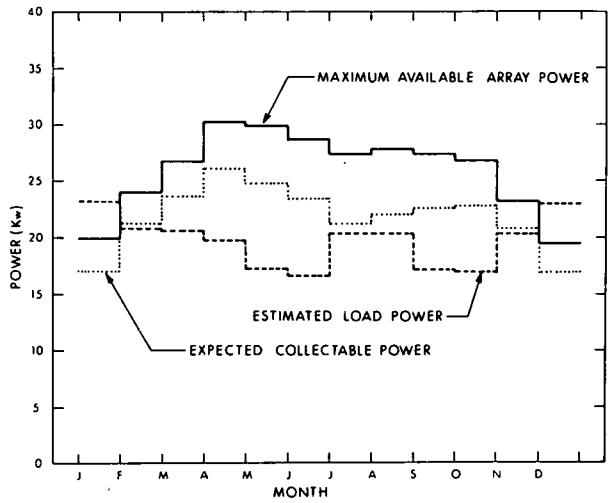


Fig. 2. Load requirements compared to available array power.

DESCRIPTION OF A CONCENTRATING PHOTOVOLTAIC ENERGY SYSTEM FOR WILCOX MEMORIAL HOSPITAL ON KAUAI

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Design and construction of Hawaii's largest solar energy system are described. This project is one of the U.S. DOE's photovoltaic application experiments to demonstrate the feasibility of generating electricity and hot water from solar energy for commercial applications. The project is sponsored by the U.S. DOE and State of Hawaii and is designed and constructed by Acurex Corporation of Mountain View, California. The Wilcox Hospital is located on the island of Kauai and like many other energy users in Hawaii is totally dependent on expensive imported oil. The hospital's electricity and heating oil bills have gone up 30 percent per year in the recent past. High cost of conventional energy and abundant solar energy in Hawaii make this demonstration project particularly important in support of Hawaii's energy self-sufficiency goal and DOE's objective of developing cost competitive alternate sources of energy technology.

The system schematic is shown in Figure 1. The major subsystems are the collector field, thermal energy subsystem, and electrical power generation. The photovoltaic (PV) collector field consists of 9,600 ft^2 of parabolic trough linear focus concentrators manufactured by Acurex Corporation. The linear receiver is populated with PV cells and is actively cooled. The parabolic trough concentrators are arranged in 10 rows. Each row consists of two groups of eight concentrators. The collectors are oriented in the north-south direction to maximize system annual energy collection. The collector coolant fluid is water that has been treated to boiler-feed water standards.

Hot water is a byproduct of the photovoltaic system which adds significantly to its economic benefits. The thermal energy subsystem consists of a closed-loop flow system, a 3000 gal hot water storage tank, a circulation pump, a diverter three-way valve, and finned tube cooling convectors. The collector rows are connected into two independent flow loops. The cold water is drawn from the bottom of the storage tank and pumped through the collector receivers to cool the PV cells and collect the thermal energy. The outlet hot water will return to the top of the storage tank. In order to maintain the storage tank thermal stratification, a diverter valve is installed to recirculate the water through the collector field if the outlet temperature is less than a minimum set point (140^oF). The operating design temperatures of the coolant are 100^oF inlet and 190^oF outlet of the collector field. The storage tank contains an immersion-type heat exchanger for heating the hospital water. The cooling convectors are installed to dissipate the excess collected thermal energy to maintain the inlet water temperature into the collector field. This ensures proper cooling of the cells and their efficient operation.

The electric generation subsystem includes the PV cells, power conversion unit, and the hospital/utility tie-in. The concentrator receiver is a V-shaped, 60^o included angle aluminum extrusion. 1 x 2 in. double bus cells are mounted on

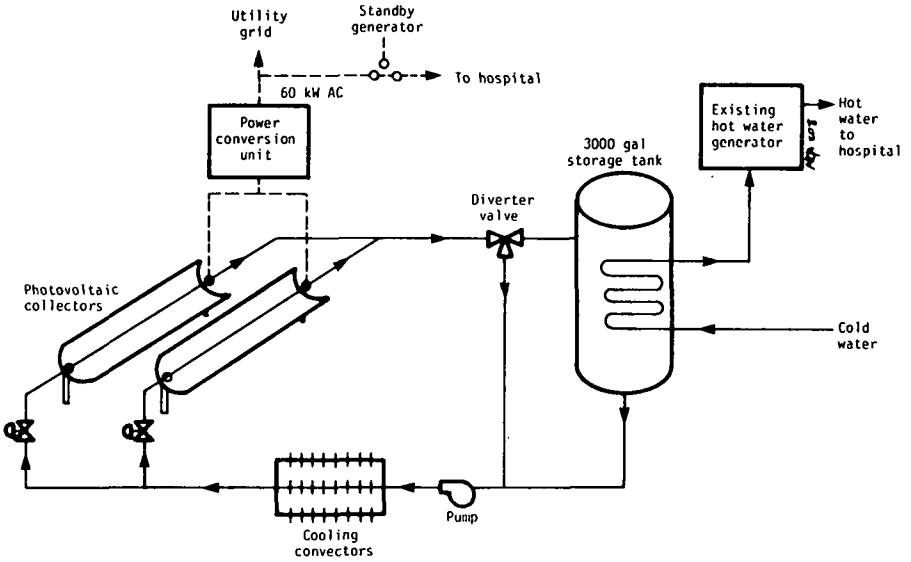


Figure 1. System Schematic

both sides of the V and are protected by a glass covering. The cells populate only 9 ft of the 10 ft long receiver to maximize annual energy generation and reduce cost. The receiver configuration was selected as a result of an extensive analytical and experimental optimization effort. At 1000 W/m^2 and 50°C cell temperature, the receiver electrical conversion efficiency exceeds 8 percent. The photovoltaic cells are electrically connected in several series and parallel circuits to attain appropriate output voltage level and efficient and safe system operation. Each receiver consists of six strings of cells connected in parallel. Each string contains 36 cells in series. A bypass diode is placed in parallel with each group of three cells to minimize shadowing effects. Sixteen receivers in every row of the collector field are connected in series. At the design conditions of 1000 W/m^2 and coolant temperature of 100°F to 190°F, one row of collectors will generate 270 VDC at 28 amps. The generated DC power is fed into a power conditioning unit to supply AC electrical power to the hospital in parallel with the local utility. The power conditioning unit is equipped with automatic peak power tracking and automatic start and shutdown capabilities. Furthermore, the solar system power output is automatically synchronized and tied-in with the utility grid. To protect utility personnel and equipment, the grid tie-in is automatically disconnected when the utility power is off. During utility brown-out periods, the existing hospital emergency diesel generators are used to stow the collectors and power system controls for safe shutdown.

The system annual thermal and electrical energy output was predicted by an Acurex computer model using 1978 weather data taken near the site. The data were collected by the University of Hawaii. An hour-by-hour computation was made for the response of each of the system components. A total of 1.4×10^6 kWh of solar radiation is incident on the aperture area of the collectors for the year. The solar system converts this into 75,000 kWh of electrical and 1.8×10^9 Btu of thermal (132,000 gallons of hot water) energy output. This will provide 2.5 percent of electrical and 73 percent of thermal load of the hospital.

The solar photovoltaic system will provide a substantial energy saving to the hospital. Furthermore, the successful completion of this DOE project is an important step to demonstrate the feasibility of solar electric generating option as a viable alternate energy source. The project is scheduled for operation by April 1981 and will be a major milestone in the State of Hawaii's stride for energy self-sufficiency.

INDUSTRIAL APPROACHES TO THE CENTRAL AND DISTRIBUTED GRID-CONNECTED PHOTOVOLTAIC MARKETS

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Introduction

The PV industry is today concerned almost exclusively with supplying stand-alone PV systems to applications remote from electricity grids. While the National PV Program has focused upon system and component developments necessary for competition with utility supplied power in order to significantly affect national energy production, the PV industry cannot and does not expect significant commercial sales in these markets for at least several years. Nevertheless, several industrial approaches and strategies for serving these markets are beginning to emerge. In addition, examination of the characteristics of grid-connected markets yields relevant information with respect to the evolution of the PV industry likely to serve them. This paper concentrates on differences in approach likely to arise between firms supplying central station markets (i.e., utilities) and firms supplying distributed or dispersed PV markets. In particular, we examine differences in PV technology, marketing, philosophy, distribution, service and product warranties and standardization.

Discussion

The Distributed Markets: Overiding concerns affecting PV product design for distributed markets include (1) safety, (2) simplicity, (3) durability (low maintenance), and (4) aesthetic attractiveness. (This assumes, of course, that the product can be made economically attractive.) Flat-plate silicon systems are clearly the class of products most likely to meet these requirements. Moderately sized systems mounted integrally with the roof structure are most likely to meet the aesthetic requirements. Maintenance of flat-plate silicon is easy, requiring nothing more than an occasional cleaning and periodic module test and replacement. System operation will be completely automated and no environmental or other safety problems are apparent.

Marketing PV products to distributed markets will require strong sales, advertising, and service activities. Markets will vary significantly by region, housing type, and buyer characteristics. New residential housing in the Southwest and Northeast in the upper middle income class is probably the most attractive distributed market. Product design and advertising should be specifically targeted to reach this market and other markets as they emerge. Sales and service organizations must be local, with selection of dealers and franchisers critical to the success of a manufacturer's product. For new construction, builders and developers will be the prime sales targets, while for retrofit markets, the homeowner himself must be sold. System installation is of critical concern, especially in retrofit applications. Strong product warranties will be essential to overcome consumer resistance to the large risks

inherent in an investment as major as a residential PV system. Given these characteristics, it is likely that the successful PV supplier to these markets will begin in one or two major cities to develop his marketing strategy, organization and management structure. After establishment of a firm base, extension to national sales coverage could proceed rapidly. The key to eventual success will be the ability to generate many hundreds of thousands of individually profitable sales.

The Utility Markets: Utilities have traditionally purchased electrical generation equipment from one of several major suppliers (e.g., Westinghouse and General Electric). While this tradition is gradually changing, the PV manufacturers may still face an uphill battle with utilities unaccustomed to dealing with new suppliers. Utilities will be primarily concerned with system cost and system performance. Comparatively complicated installation, service and operation can be accepted if benefits in costs and performance are anticipated. This implies that more complicated systems (e.g., tracking, concentrators, new materials) are feasible, assuming their life-cycle performance can be reasonably well predicted. The utility will be quite concerned about the general reputation, technical expertise, and financial well-being of potential PV suppliers. Does the supplier guarantee performance? Will he be willing and able to assist the utility with unforseen difficulties as they arise throughout the life of the PV plant? Demonstrations of system performance over significant lengths of time (5 years) under realistic conditions are extremely beneficial, if not essential, for large utility commitments to any particular PV system concept.

Given the likely size of utility orders (50 MWp = 5000 homes at 10 kWp/home), a large marketing and sales organization is not required. More importantly, utility customers must be cultivated early. Small demonstrations with the PV manufacturer sharing the costs and risks while the utility gains early PV experience could lead to orders of thousands of megawatts. Expertise and advice with respect to the likely effects of PV on utility operations, stability, reliability and grid interconnection of the PV system will be highly valued by the utility and should be included as part of the services supplied with the PV system.

Conclusion

Industrial approaches to photovoltaics are likely to differ substantially between the distributed and central station markets. Sales, service, and installation organizations must be emphasized in distributed applications. The PV product must be relatively simple and rugged. In contrast to this, sales organizations for central markets need little attention and much more complicated PV products can be successful if performance or cost is improved even marginally, although reliability of performance is important as well.

These differences could easily lead to specialization of PV manufacturers according to the market they serve. The ultimate success of any particular manufacturer may, therefore, be tied to the ultimate attractiveness of distributed versus central PV applications.

MARKET SEGMENTATION - THE KEY TO SUCCESS

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Introduction

The photovoltaic energy system is a very difficult product to determine the markets served as the cost is decreased to the point that PV systems are economic for virtually all electricity generation. The owner benefits that sell PV will be complex and varied and far more subtle than the "economic break even" criteria used by DOE and public market research done to date. The many unique attributes of PV systems tend to open up a vast array of diverse applications and customers - many of which represent billion dollar world wide annual markets before PV systems are economic for massive deployment in competition with grid-connected electricity. This paper will segment the market by trying to associate PV system attributes other than economics to several specific user needs. The purpose will be to challenge our private sector market research community to develop the analysis which calls for PV products that can sell the oft-discussed "intermediate market." That is, the product that can be sold before PV systems are fully economic for grid-connected applications. Finally a scenario is developed, for early subsidized economic viability and sales for U.S. residences. The possibility exists that economic PV residential systems will begin mass marketing by 1982 rather than the 1986 planned by DOE.

Attributes Of PV Systems Other Than Cost

Some of the attributes of PV systems which will stimulate product sales to new users are obvious. This section will try to stimulate creativity in the use of these attributes to develop and sell PV systems. A small sample of those attributes are listed below. The reader is encouraged to expand the list and to define specific PV products which can be sold to specific persons. This, of course, is market segmentation in its most elemental form. The attributes of PV systems that could lead to early non-economic sales of PV systems include:

> Reliability - no moving parts - silence - portability - can be folded into small volume - no fumes or gases - can be very small power (microwatts) - can be large multimegawatt power stations - will run on fluorescent light - can work on North facing walls - can be integrated into roofs, windows, walls, canopies, tops of cars, trucks, trains - Works while in motion - is modular for repair - can be installed quickly on almost any surface that receives sun - Is directly compatible with batteries - generates direct current at almost all voltage levels - can lead to energy self reliance - PV is solar energy - uses no fuel - Will enjoy large federal subsidies.

Applications And Users That May Value These Attributes Over Cost - And Represent Early Markets

As one segments the PV market, sets of applications/users can be identified that may purchase PV systems before they are fully economic. Some examples of these are listed below:

- Users who value fixed electricity costs.
- Persons and communities that want energy independence and self reliance over grid supplied electricity.
- Nature lovers who want some electricity but demand silence - campers, sail boats.
- Persons who want reliable remote power - starter batteries for boats, airplanes - remote communication, remote sensing, remote signals, remote vacation cabins.
- Persons who want to be first on their block with PV power on their roof - the "first nighter" market.
- Persons who are tired of purchasing batteries for watches, calculators, electronic toys, games and prefer long-lived internal light recharging systems.
- Persons who want to replace physical drudgery with electrical power - micro-irrigation by electricity rather than by ox or man.
- Person who want portable power - small refrigerators, portable communications, electronics.

The Opportunity

The task of the market analyst is to target these PV attributes to specific customers, define and test the product, and commit to sales forecasts that cause risk capital to be spent on PV product development. The opportunity for significant sales to these early, non-economic markets appears to be much larger than published to date.

The Private Residence

A simple, break-even analysis for the PV powered residence in the Southwest shows that a $2,000/kW peak PV system can generate electricity at 6 cents per kilowatt hour; if the 30 year home mortgage costs 12%, marginal tax bracket is 35%, and the utility credits the owner 3 cents/kWh and charges 6 cents/kWh when the PV system is off.

If we take this same product and find a potential user that is really desirous of having a solar house, wants to take advantage of every incentive and is happy with 10 cents/kWh on the basis that in two years electricity will be 10 cents anyway. Assume this "first nighter" -

- Gets the same 12% 30 year loan - Has a builder that took advantage of the California 55% tax rebate - Takes advantage of the 40% of $10,000 federal tax rebate - Has a utility that must pay 12 cents for peak electricity and can charge only 4 cents/kWh for night recharging - Is in the 50% tax bracket - Buys a small, $10,000 system.

One can see now see that at $5,000-6,000/kWh system resulting in 10 cents kilowatt electricity before rebates is equivalent to the $2,000/system with its 6 cents/kWh systems. In other words by carefully selecting the customer we have identified an early market in 82 rather than the present 86 goal of DOE.

FEDERAL STRATEGIES FOR AGGRESSIVE PHOTOVOLTAIC MARKET DEVELOPMENT

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The combination of all photovoltaic power systems installed under U.S. Department of Energy (U.S. DOE) funding and by U.S. industry sales to non-U.S. DOE buyers amounts to 3 to 5 Mwp power capacity. Total costs for these systems are in excess of 100 Million U.S. Dollars. Less than one percent of the U.S. sponsored installations are remote, stand-alone systems, while nearly 100 percent of the U.S. industry sales to non-U.S. DOE buyers are for remote, stand-alone systems.

On the other hand, DOE sponsored and industry sponsored market studies clearly show that the largest potential markets are non-remote applications which generally are expected to be grid connected in the U.S. For example, DOE's Residential Application Implementation Plan (1) claims:

- If half of all new residences built from 1985 to 2000 are equipped with photovoltaic systems, between 1.0 and 1.5 primary quads would be displaced (such a penetration would require 50% x 19.6 x 10^6 units x 8 kWp per unit = 78.4 GWp cumulative installed capacity).

- If ten percent of all residences existing in 1985 are retrofitted by 2000 with photovoltaic systems, approximately 10% x 88.8 x 10^6 units x 50% of required energy x 60 MWh per unit per year = 266 TWh (1 quad) would be displaced. (such a penetration would require 10% x 88.8 x 10^6 units x 6 kWp per unit = 53 GWp cumulation installed capacity).

Similar projections for commercial/industrial/institutional applications show significant market potential. Furthermore, utility central power application potential markets are very promising, particularly municipal utility applications (2). One study (3) projected a large-scale implementation which would result in nearly 1000 GWp cumulative installations by the year 2000.

The DOE Photovoltaic Program has been engaged in an extensive, comprehensive effort for nearly six years. More than one-half billion dollars have been expended in advanced research and development, technology development, systems engineering and standards, test and applications, and commercialization. This program covers work in materials, components, subsystems and systems.

In examining both the potential for photovoltaic markets and the extensive DOE program there is, however, a question which can be raised: Are there any further Federal Strategies which could be implemented to accelerate the present market development to meet the full market potential?

This paper discusses two strategies which are proposed for accelerating market development. Both strategies focus on the system application activities. This focus follows from conclusions drawn in Reference 4.

The first strategy discussed considers the means to maximize the use of the existing building-construction infrastructure in the Program system applications program. The strategy is shown to be optimal for accelerating market development on the basis that any other approach acts as an impediment to acceleration. Examples of this effect are presented.

The second strategy presents an approach to developing system applications which will increase the attractiveness of photovoltaic systems in building applications. It is argued that following a specified approach to system application design will provide earlier cost-effectiveness thereby accelerating market development.

The system application design approach considers six key elements in application design: (1) energy conserving building design, (2) building mechanical design to shift demand, (3) photovoltaic power system sizing, (4) efficient loads design, (5) siting and (6) utility energy costs and rate schedules. Examples of this approach are presented.

REFERENCES

1. Massachusetts Institute of Technology, Energy Laboratory, Lincoln Laboratory, "Residential Application Implementation Plan", Draft, September 1979.

2. Leonard, S.L., B. Siegal, The Aerospace Corporation, "New Perspectives on Market Prospects for Photovoltaic Central Station Power Plants", Report No. ATR-80(7820-04) - 1, El Segundo, CA., January 1980.

3. MONEGON, Ltd., "Distributed Solar Electricity 1980-2000: Transition from Monopoly to Competition in Electric Power Generation", Gaithersburg, Maryland, June 1980.

4. Macomber, H.L, et al., "Photovoltaic Applications-Past and Future", 14th IEEE Photovoltaic Specialists Conference - 1980, Conference Record, IEEE Catalog No. 80CH1508-1, 1980.

SECTION 6

SOLAR THERMAL

SOLAR THERMAL

Program Chairman: *J. C. Grosskreutz,* Black & Veatch
DOE Advisor: *Gerald Braun*
Overview Presentation: Thursday, December 11, 11:00 A.M.

"Solar Thermal Energy System Program Overview" 2-102
Gerald Braun, DOE

SESSION I: Tuesday A.M.
Solar Thermal Technology Development–Past, Present and Future

"Overview of DOE Solar Thermal Technology Development" 6-1
James E. Rannels, DOE, and *Joseph Lenore Meglen,* PRC/Energy Analysis Co.
"Parabolic Trough Development: Lessons Learned at Willard & Gila Bend" 6-3
Virgil L. Dugan, Sandia National Laboratories
"Central Receiver Technology" 6-5
William G. Wilson, Sandia National Laboratories
"Parabolic Dish Technology" 6-7
Vincent C. Truscello and A. Nash Williams, Jet Propulsion Laboratory
"The Crosbyton Solar Power Project: The Hemispherical Bowl Concept" 6-9
John D. Reichert, Texas Tech University
"A Review of Solar Test Facilities" 6-11
Billy W. Marshall, Sandia National Laboratories

SESSION II: Tuesday P.M.
Systems and Applications I

"10 MWe Solar Thermal Central Receiver Pilot Plant" 6-13
Joseph N. Reeves, Southern California Edison Company, and
Richard N. Schweinberg, DOE
"Repowering/Cogeneration: Electricity and Industrial Process Heat Using Central Receivers" 6-16
Robert W. Hughey, DOE/San Francisco
"Solar Hybrid Full System Experiment" 6-18
Don Bartlett and Ron Zentner, Boeing Engineering and Construction Company
"International Energy Agency Projects in Spain" 6-20
Alvin F. Baker, Sandia National Laboratories
"Solar-Powered Irrigation Facility Demonstration, Coolidge, Arizona" 6-22
J. O. Vindum, Acurex Solar Corporation

SESSION III: Wednesday A.M.
Systems and Applications II

"The Solar Total Energy Project at Shenandoah, Georgia" 6-24
R. W. Hunke, Sandia Laboratories, *A. J. Poche,* General Electric Company, and
J. A. Roberts, Georgia Power Company
"Enhanced Oil Recovery" ..... *
Jeff Hamilton
"The Small Community Solar Thermal Power Experiment" 6-26
Joseph Weisiger, DOE
"Operation and Design of Selected Industrial Process Heat Field Tests" 6-28
D. W. Kearney, Solar Energy Research Institute
"Salton Sea Project" 6-30
Robert L. French, Jet Propulsion Laboratory, and *Igal Meitlis,* Southern California Edison Co.

*Abstract not available for printing in Conference Proceedings

SESSION IV: Thursday A.M.
Solar Thermal Research and Advanced Development

"Solar Materials Development" 6-32
Barry L. Butler, Patrick J. Call and Patricia A. Roberts, Solar Energy Research Institute

"Component Research and Technology Development" 6-35
J. M. Lefferdo and B. P. Gupta, Solar Energy Research Institute

"Advanced Systems Development" 6-37
John C. Becker, Jet Propulsion Laboratory

"Thermochemical Energy Conversion and Transport–Development of Concepts" 6-39
J. H. McCrary, New Mexico State University

"Fuels and Chemicals Research and Experiments" 6-41
Charles B. Benham, Solar Energy Research Institute

SESSION V: Thursday P.M.
Market Development

"The Role of Quality Assurance and Standards in Developing Solar Thermal Commercialization Technology" 6-43
Harold R. W. Cobb and Gary Nuss, Solar Energy Research Institute

"Innovative Financing for Industrial Applications of Solar Technology" 6-44
William C. Dickinson, Lawrence Livermore National Laboratory, and *Charles B. Wilde,* Winthrop Financial Co., Inc.

"Industrial Process Heat Case Studies: Potential for Solar Thermal Applications" 6-46
E. Kenneth May and David L. Feasby, Solar Energy Research Institute

"Agricultural Solar Research Programs – An Overview and Highlights" 6-48
Landy B. Altman, USDA-SEA, *Paul R. Barnes,* Oak Ridge National Laboratory, *James L. Butler,* USDA-SEA, *Conrad V. Chester, and James M. Schreyer,* Oak Ridge National Laboratory

"Solar Enhanced Oil Recovery, A Potential Early Market for Industrial Solar Energy" 6-50
Kenneth D. Bergeron and Virgil L. Dugan, Sandia National Laboratories

OVERVIEW OF DOE SOLAR THERMAL TECHNOLOGY DEVELOPMENT

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Joseph Lenore Meglen
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Federal involvement in solar thermal technology development began in 1971 with initial funding provided by the National Science Foundation. Another Federal effort was sponsored in 1973 through the Atomic Energy Commission. These programs were consolidated under the Energy Research and Development Administration in 1975 and transferred in 1977 to the officially chartered Department of Energy (DOE). Today Federal funding has reached a level of $155.5 M, as shown below, and reflects the growing public awareness of the need for renewable energy sources.

TABLE 1. Federal Funding of Solar Thermal R&D (Millions of Dollars)*

FY 71	72	73	74	75	76	77	78	79	80
0.06	0.55	1.43	2.20	13.2	26.9	66.6	104.1	100.1	156.0

* Includes Capital Equipment Construction Funding

The President, in his June 20, 1979 message to Congress, established as a national goal the use of solar and renewable resources for 20% of our energy needs in the year 2000. The Domestic Policy Review (DPR), also prepared under his direction, has assigned specific goals for each solar technology: in the case of solar thermal, three quads of primary fuel must be displaced by the year 2000, with 2.6 quads in industrial process heat production and 0.4 quads in electricity generation. In accordance with these goals, the Technology Development Branch (TD), within the Division of Solar Thermal Energy Systems, has the following objectives: 1) to provide the technology base upon which domestic industry can build a viable solar thermal market; and 2) to assure the development of solar thermal products within U.S. industry which can be applied in the commercial market. These objectives are being met by DOE sponsorship of solar thermal technology development through laboratory field centers and by close cooperation with the commercial industry and potential users.

Technologies currently under development by DOE are central receiver systems at Sandia National Laboratory, Livermore (SNLL), parabolic troughs and hemispherical bowls at Sandia National Laboratory, Albuquerque (SNLA), and parabolic dishes and naturally occurring solar ponds at the Jet Propulsion Laboratory (JPL). Decentralized management is provided by the Albuquerque Operations Office to each of the above field centers responsible for solar thermal technology development. The program has been structured to be user oriented with applications including mid- and high-temperature industrial process heat (IPH); electricity generation for utilities, small communities, isolated areas, islands and irrigation; and cogeneration.

Central receiver systems have been emphasized for centrally located electrical power production and large IPH and cogeneration applications. SNLL is conducting advanced receiver development using molten salt and liquid sodium working fluids, in addition to water/steam and hot air. Second generation heliostats (first generation heliostats are used in the Barstow project), as well as storage technology for all solar thermal systems, are also under development at SNLL. The

molten salt receiver and second generation heliostats will be incorporated into the Repowering/Industrial Retrofit Project within the Systems and Applications Program. The Central Receiver Test Facility at Albuquerque, New Mexico, under SNLL management serves as the site for actual testing of all prototype hardware before its use in any full-scale experiments and projects.

Parabolic trough systems have been used to provide electricity for shallow and deep well irrigation experiments and mid-temperature industrial process heat. SNLA is now developing with industry improved components for the Performance Prototype Trough, while the Modular Industrial Solar Retrofit Project (MISR) will emphasize system-level design and fabrication of existing collector technology for IPH applications. These systems will be used in 5-10 experiments and will require industrial user and A&E participation in site preparation, construction, and system operation. The Mass-Producible Collector Project includes electrical power generation applications in addition to IPH. Its purpose is to sponsor industry design of mass-producible collectors and related components that will decrease overall system cost.

SNLA is also directing hemispherical bowl development, a more recent addition to the solar thermal TD Program. The 65 ft. diameter prototype bowl in Crosbyton, Texas has been operating successfully since January, and to date the performance has been close to theoretical predictions. Although preliminary studies indicate its suitability for electrical power generation in small communities, islands and isolated areas, the decision to proceed on scale-up will be made in mid-FY 1981 after a detailed cost and performance review.

Prototype testing for all components and systems under development at SNLA is conducted at the Mid-Temperature Solar Systems Test Facility in Albuquerque, New Mexico. Commercial test facilities are also being qualified by SNLA throughout the U.S. for system, subsystem, and component testing of troughs.

JPL is directing parabolic dish and naturally occurring solar pond technology development for DOE. Due to their inherent modularity and high concentration ratios, parabolic dishes are well suited for electric power generation in isolated, remote areas and in small communities. Prototype steam and gas receivers, as well as Rankine and Brayton engines for power conversion, are now undergoing test and evaluation at the Parabolic Dish Test Site (PDTS) in Victorville, California. Two Low-Cost Concentrator designs will be fabricated later this year and also tested at PDTS. One of these two competing prototypes will be selected for use in the Small Communities Project within the Systems and Applications Program. Thermal and/or electric applications for parabolic dishes are being studied in a TD Engineering Experiment by JPL.

Recently JPL initiated a feasibility study of using a portion of the Salton Sea to produce electricity. This concept appears particularly attractive since it may provide not only an economical source of electricity but also serve to reduce the environmental hazard due to the increasing salinity of the Salton Sea.

These efforts represent a directed approach by DOE to solving not only the engineering and related problems of current solar thermal technology but to advance it even further. Because significant achievements have been made, initial commercialization is expected in 1985 for parabolic troughs, 1987 for parabolic dishes, and 1989 for central receivers. Hemispherical bowls and solar ponds still require further development and evaluation due to their late entry into the program. Close cooperation with industry and potential system users is vital to the continued success of the TD program. Only by reducing overall system cost, and increasing system reliability and durability can our goals be met.

PARABOLIC TROUGH DEVELOPMENT: LESSONS LEARNED AT WILLARD & GILA BEND

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The Arab oil embargo of 1973 initiated an accelerated investigation of alternative energy sources in this country; one of these new possibilities to be investigated was solar energy. A specific area of concern during this time period was that of irrigated agriculture since the availability of fossil fuels for this use was in question. Consequently, agricultural irrigation was selected as an initial opportunity for sponsoring the development of small solar mechanical/electrical power systems.

Two system designs were initiated in the 1975-1976 time frame: the DOE/New Mexico Shallow-Well Irrigation Project at Willard, New Mexico, and the Northwestern Mutual Life Insurance Company Irrigation Project at Gila Bend, Arizona. A particularly unique aspect of each of these endeavors was that all system design work as well as component and subsystem development work was done concurrently. The results were the first generations of commercial solar thermal parabolic trough hardware as well as the first modern attempts to employ this solar conversion technology in a system providing mechanical or electrical power.

The Willard shallow-well irrigation system began operation in July of 1977 with 625 m^2 of Acurex parabolic troughs being used to provide heat at 216°C to drive a 19 kW organic rankine cycle turbine. Storage was also provided in two formats: 26 m^3 of sensible heat thermocline storage and a 5560 m^3 holding pond. Later an additional 651 m^2 of Solar Kinetics parabolic troughs and 26 m^3 of storage were added.

The Gila Bend tail water irrigation system, which was designed by Battelle, Columbus Laboratories, began operation in April of 1977 with 537 m^2 of Hexcel parabolic troughs being used to provide heat at 150°C to drive a 38 kW organic rankine cycle turbine. No storage was incorporated into the system design.

Each of these activities has served to establish a baseline for parabolic trough concentrator technology development within a true systems framework and has identified the areas of needed improvement. Both of the systems mentioned have clearly demonstrated the technical reality of using concentrated sunlight to operate a heat engine which produces mechanical power in an energy efficient operation. On the other hand, the three years of solar irrigation system operation have demonstrated that the operating and maintenance requirements for the first generation of solar technology and for the available, small, organic rankine cycle turbine technology is excessive and will not allow economical operation by an independent farming community. Improvements in the subsystem technologies and the construction of larger systems (e.g., 1.0 MW_e) will provide a significant improvement in the overall economic feasibility of these systems.

More specific lessons learned from three years of operating experience are:

Collectors -

- o Alzak is a relatively poor quality reflector material; FEK has degraded only slightly in three years of use.
- o Glass receiver jackets must be kept clean if used. Operation at lower temperatures (≤150°C may be more economical without receiver jackets.
- o Simple shadow-band trackers operating alone are inadequate.
- o Materials with low maintenance requirements are imperative.

Energy Transport -

- o Flex hose integrity and reliability is key to system safety.
- o Heat transfer fluid leaks can initiate unsuspected fires.
- o Fluid manifold and collector interconnect design must consider loss mechanisms often neglected in standard practices.

Engine -

- o Turbines should be hermeticallly sealed to improve O&M requirements.
- o Diurnal cycling (start-stop) of engine operation complicates engine maintenance.

Storage -

- o Multi-tank thermocline storage operates efficiently.

CENTRAL RECEIVER TECHNOLOGY

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The central receiver concept is one of the more promising approaches for collecting the sun's energy to fuel high temperature industrial processes. With this approach, a field of individually controlled reflectors, or heliostats, redirects the sun's rays to a receiver on top of a tower. In the receiver the concentrated solar flux is absorbed in a circulating working fluid which can be used to power a conventional turbine or operate an industrial process. Recent studies indicate that solar central receiver plants using mass produced heliostats may soon be economically competitive with more conventional coal and oil fired plants. This development is mainly due to two factors: (a) the rapid escalation in fossil fuel alternatives, and (b) the improved cost/performance of central receiver components through an aggressive research and development program. Research on the concept was initiated in the United States by the National Science Foundation in 1972. Since that time, the program has been expanded into a major research and development effort by the Department of Energy's Division of Solar Thermal Energy Systems.

The heliostat field represents the major element of the total plant cost (from one-third to one-half, depending on the specific application). As such, it is the single most important subsystem for cost leverage. Two basic approaches have been used to project low manufacturing costs for heliostats which have the necessary performance characteristics. The first approach is to attach structurally reinforced glass mirrors to a rigid metal framework. The second design approach uses an air-supported transparent dome to provide environmental protection to light weight plastic reflectors. Prototypes of each of these approaches have been fabricated and tested.

By the end of calendar year 1980, the United States central receiver program will have demonstrated the performance of over 30 prototype heliostats designed and fabricated by 9 different industrial teams. In addition, several years of operation of the 222 heliostats at the Central Receiver Test Facility in Albuquerque will have been accumulated. By the end of 1981, an additional 1800 heliostats will be in operation at the Barstow 10 MW_e pilot plant, and 5 different advanced designs intended for repowering applications will have been evaluated. Technical feasibility has been demonstrated for heliostats; what they will cost when mass produced remains unclear.

Even though the heliostat field capital cost is the major economic driver for the central receiver concept, the receiver subsystem has a major influence on the heliostat field size and the thermal to mechanical conversion efficiency which in turn affects the total system cost. Under active development at this time are receivers employing water/steam, sodium, molten salts, air and heat transfer oils. Major experimental efforts to date have been limited to water/steam and high temperature air receivers, but active efforts are underway to characterize the advantages of other working fluids. In particular, a 5 MW_{th} molten nitrate salt receiver experiment is nearing completion at the Central Receiver Test Facility. It will be followed early next calendar year by a liquid sodium cooled experiment.

Major considerations impacting the development of solar thermal power systems for commercial applications are the need to provide continuous operation during periods of variable insolation, to extend operating periods into nonsolar hours, to buffer potentially harmful transients induced into systems by abrupt insolation changes, and to assure the availability of productive capacity in emergency periods. Two options exist for meeting these requirements: conventional backup systems and thermal storage. Backup systems provide a viable near-term solution. However, as conventional fuel supply becomes critical due to cost or availability, thermal storage will assume an increasingly important roll. Storage designs compatible with each receiver fluid are under development.

When the heat transfer fluid in the receiver is also used as the storage media, costly intermediate heat exchangers can be avoided. If, in addition, the receiver fluid displays the appropriate thermodynamic properties for storage needs, a cost effective thermal loop (e.g. receiver plus storage) system can be considered. This is the case with the nitrate salt working fluids being investigated. At this time this approach shows a 15 to 30 percent improvement over advanced water/steam and liquid sodium at least as far as electric power production is concerned. Hence, the engineering parameters affecting system application designs using nitrate salts are the subject of vigorous research. As the program gets a better understanding of process heat applications, a clearer picture of the relative merits of all receiver working fluids for these uses will be obtained.

A number of important achievements have been accrued for the central receiver program since its inception. The Central Receiver Test Facility, a major test facility for the evaluation of large scale components, has been operating for two years. Several iterations on heliostat receiver and storage component designs have been fabricated and tested. A 10 MWe pilot plant is under construction which will provide the first operational experience with an integrated system. A series of site specific studies have been completed to evaluate the potential of this technology in repowering existing electric plants and retrofitting a variety of industrial processes. At this time, actions are being taken within DOE to pursue the construction of plants for several of these applications. These efforts have been coordinated to achieve successful commercialization of this technology by the early 1990's. Whether or not large scale energy production will be realized after that will depend on the marketplace evaluation of available alternatives.

PARABOLIC DISH TECHNOLOGY

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This paper summarizes the status of the Parabolic Dish Project managed by the Jet Propulsion Laboratory for the U.S. Department of Energy. The objectives of the project are to develop the technology for parabolic dish solar collector systems and lay the groundwork for their subsequent commercialization. Dish systems can provide heat over a temperature range of 700 to 3000°F (370-1650°C) for users of process heat. For electric applications, a heat engine/alternator package is integrated with a receiver located at the focal point of the dish. The Low Cost Concentrator (LCC) manufactured by the General Electric Company (GE) is a first-generation dish 12 meters in diameter and is shown in Figure 1.

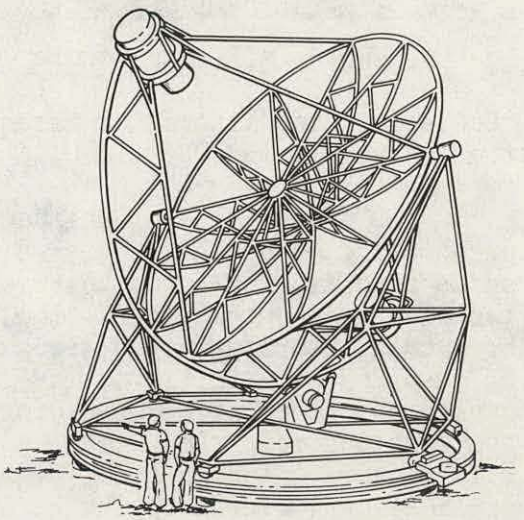


FIGURE 1 General Electric Low Cost Concentrator

Three markets for parabolic dish systems have been identified: (1) small communities, generally grid-connected; (2) remote or isolated electric load markets; and (3) industries that require process heat or a combination of heat and electricity. Validation of the evolving technology of dish systems in these user environments will be accomplished through a series of engineering experiments in each of these market segments. These experiments are referred to as the EE 1, EE 2, and EE 3 series, respectively.

The first experiment in the EE 1 series is called the Small Community Solar Thermal Power Experiment (SCSE). It is a one-megawatt electric plant for which the Ford Aerospace and Communications Corporation (FACC) has been awarded a systems contract for plant design. The location of the plant will be determined upon completion of the site selection process, which began with a solicitation by DOE in the form of a Program Research and Development Announcement (PRDA). Forty-five responses were received from communities throughout the United States. Of these, six have been selected for in-depth evaluation. The selected community, its local utility, and the system contractor will execute the experiment with management from JPL. The dish module for the SCSE is made up of the GE LCC, a receiver designed by FACC, and a power converter being developed by the Barber-Nichols Engineering Company.

The EE 2 series for isolated applications must have stand-alone characteristics due to the absence of an electric grid. The first of the experiments is a 100-kWe Military Module Power Experiment (MMPE), co-funded by DOE and the Navy. The site selected is the Marine Corps Air Station in Yuma, Arizona, and is illustrated in Figure 2. The components of the collector are the GE LCC, described earlier, and a receiver and Brayton-cycle air turbine power converter designed by the Garrett AiResearch Manufacturing Company of California. The integrated

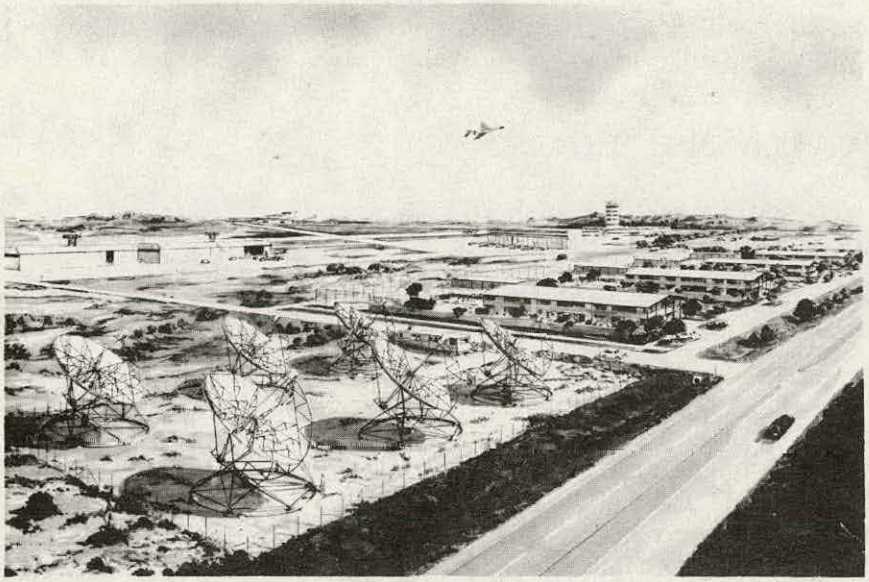


FIGURE 2 Military Module Power Experiment

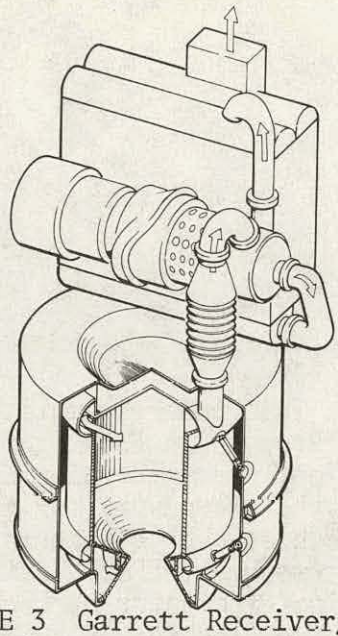


FIGURE 3 Garrett Receiver/ Engine/Alternator Assembly

receiver/engine/alternator assembly is shown in Figure 3. The turbine inlet design temperature is 1500°F (816°C).

The EE 3 series of engineering experiments began with the 400-kWe total energy plant designed by the General Electric Company to provide electricity, steam, and space conditioning for a knitwear factory in Shenandoah, Georgia. Installation of the plant will begin in FY 81. The experiment is being technically managed for DOE by Sandia Laboratories in Albuquerque, New Mexico. Additional experiments in the EE 3 series were initiated in FY 80 with the award of several contracts for the design and fabrication of prototype hardware. The contracts address different applications requiring steam and heated air, with or without electricity. Enhanced oil recovery in which a hot liquid is injected into the well is included among the applications covered by the EE 3 series.

All of the engineering experiments and the economic readiness tests to follow are supported by an extensive technology development effort involving many contractors. All subsystems and complete dish modules are tested for compatibility, performance, and durability at JPL's Parabolic Dish Test Site (PDTS), shown in Figure 4, which is located in the Mojave Desert, California. Testing at the PDTS assures confidence in the technical success of the engineering experiments. The experiments themselves will verify that the integrated dish module arrays can meet the economic goals necessary for their subsequent commercialization -- which is the primary project objective.

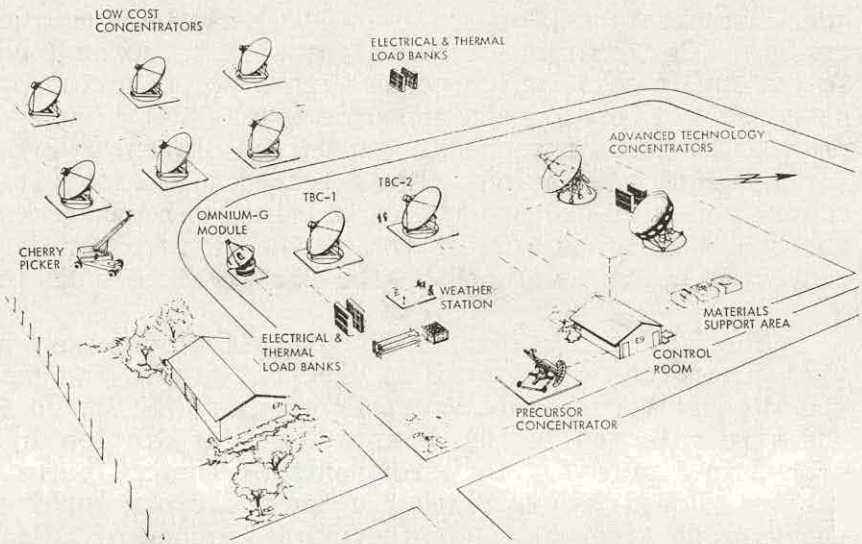


FIGURE 4 Parabolic Dish Test Site

THE CROSBYTON SOLAR POWER PROJECT: THE HEMISPHERICAL BOWL CONCEPT

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The Crosbyton Solar Power Project (CSPP) is a project of the United States Department of Energy, funded in steps since September 1, 1976. The prime contractor is Texas Tech University, Lubbock, Texas. E-Systems, Garland, Texas, has served as the principal subcontractor since the inception of the work. Foster Wheeler Energy Corporation, Livingston, New Jersey, and other subcontractors have participated in the work. The total funding for the project to date has been $5.2 million. The most visible accomplishment of the CSPP has been the design, construction, and operation of the largest single solar collector ever built. This collector is called the Analog Design Verification System (ADVS) and was established as a tool required to provide data in support of the research and development aspect of the project mission. The mission of the CSPP is: to perform research, development, testing, and evaluation activities as required to determine and specify a promising conception of a 5 MW_e solar-thermal fossil-fuel hybrid electric power plant for Crosbyton, Texas; to develop a modeling and prediction capability for reliable and justifiable estimation of the performance and cost of such a plant; to determine, therefrom, the utility of actually building the plant; and, should it be justified, to build the plant and put it on-line. The CSPP was funded as a sole source contract offering development of a fixed aperture spherical segment collector which Texas Tech calls the Solar Gridiron to connote ideas for both large size and heat. The concept is commonly called the Hemispherical Bowl Concept, but has also been known under the names Fixed Mirror Distributed Focus (FMDF), Solar Bowl, and PERICLES. In spite of the many names, there are only two projects dealing with the concept: the USDOE-Texas Tech CSPP, and the French CNRS PERICLES project. These two projects are complementary in the sense that they differ noticeably in component design, working fluid, thermodynamic cycle, initial applications target, and so forth.

The application site of the CSPP is Crosbyton, Texas, a town of population 2,500 located in the Texas panhandle, 38 miles east of Lubbock. This specific site provides a very realistic context for the project application target. Crosbyton is by no means an "ideal solar site", but is, rather, a valid representative site, typical of a vast geographical region of the earth which might be called "the Sun Belt". The present Crosbyton Municipal Electric Power Plant burns fuel oil and natural gas in diesel engines to provide somewhat less than 5 MW_e of peak demand. Crosbyton has an average wind speed of 18 miles per hour and is subject to dust storms, rainstorms, hail, ice, snow, tornadoes and other "realistic" climatic features including clouds, a long hot growing season for its cotton crop, and a adequate supply of bright sunlight. To preserve the realism and context of the program, the 65-foot aperture diameter ADVS was built at Crosbyton at the same location reserved for the 5 MW_e power plant possibly to follow.

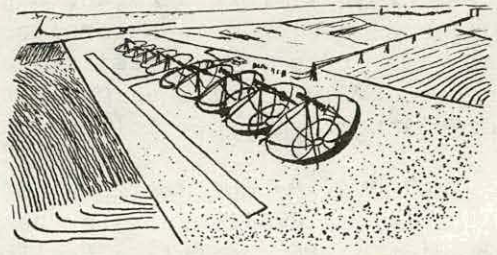
The ADVS was not designed as a working device for some specific application. Rather, it was designed as a research tool to gather data to provide a basis for extrapolation to the full size, 200-foot aperture diameter, power plant dishes. The ADVS, at 65-foot aperture diameter, is a one-third linear scale, a one-ninth power scale model of the planned 200-foot power dishes. The collector mirror shape is a

spherical segment of rim angle 60°; i.e., an included rim-to-rim central angle of 120°. The Crosbyton latitude is 33.6°, so the ADVS mirror is tilted 15° southward to provide an "effective latitude" of 18.6° for the aperture. The ADVS mirror is composed of 430 panels or facets, each 39 inches X 39 inches and each pre-curved to the spherical radius of curvature, 37.5 feet. The reflecting surface is 3/32 inch thick glass over a chemically deposited silver layer, supported by a paper honeycomb structure impregnated with plastic. The panel is backed with sheet metal with a fiberglass close-out.

The argument favoring a fixed aperture collector recognizes the diffuse nature of solar input power and the consequent size required for a 5 MW_e power plant. Mirror structures of large aperture able to deliver intense, steady focal concentrations in the presence of strong winds (average: 18 miles per hour; peak operational: 60 miles per hour; survivability: 90 miles per hour), will necessarily be sturdy and, therefore, heavy. Movement of heavy mirror structures in precise fashion would lead to electrical parasitics and substantial control problems, both of which are likely to substantially reduce the cost effectiveness of the plant. For fixed aperture applications, the spherical segment mirror offers two major advantages: 1) that the focal region has an excellent shape, distributed over a linear (conical) region, providing excellent heat transfer surface area, and 2) that the spherical symmetry (lack of a strongly preferred axis) allows congruency in the shape of the focal region throughout the solar day.

The ADVS boiler is composed of two quarter-inch ID tubes of Inconel 617, each 400 feet in length, closely wound as helices on a small diameter (6-inch) support cylinder 18 feet long. Water introduced at one end of these two parallel flow paths, the end closest to the mirror, exits as steam from a manifold at the other end of the boiler. The boiler is supported and tracked by means of a cantilever support pivoted at the center of curvature of the sphere. The pivot point is supported by a tripod structure and the fluid lines are articulated with flexible hoses at the pivot point.

The ADVS became operational on January 23, 1980 and has been operated continuously up to present time. At its first trial (in front of 300 spectators) it sounded a steam whistle loaned to CSPP by Santa Fe Railroad. This performance test was conducted under gentle receiver exit conditions: 500 psi, 550°F. Two days later the system was taken to design conditions - 1000 psi, 1000°F - and tested successfully. Design expectations for the system were that about 60% of the input optical power would be absorbed by the working fluid. This expectation has been completely confirmed by the data. A great deal of data is being gathered from the 150 sensors and transducers and is being recorded. Detailed analysis of the data are underway and will continue for about a year. If the results continue to be encouraging then perhaps someday ten 200-foot gridirons will provide solar power to a 5 MW_e power plant at Crosbyton, Texas. The ADVS system is operated all day long, seven days a week. Should you find it convenient to visit Texas Tech, Crosbyton, the ADVS site, or our ultimate demonstration, you can expect to be received with a hot sun and warm Texas hospitality!



5 MW_e Solar Gridiron Power Plant Planned for Crosbyton, Texas

A REVIEW OF SOLAR TEST FACILITIES

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A number of high-flux solar test facilities have been placed in operation in the United States. The earliest in operation was the 30kW$_t$ White Sands Solar Facility (WSSF) operated by the U.S. Army at White Sands, New Mexico. The U.S. Department of Energy's solar thermal program has been responsible for development of the remaining facilities. These include the 5000kW$_t$ Central Receiver Test Facility (CRTF) located near Albuquerque, New Mexico; the 325kW$_t$ Advanced Component Test Facility (ACTF) located at Atlanta, Georgia; and the Parabolic Dish Test Site (PDTS) located at Edwards Air Force Base, California. In addition a 5kW$_t$ Furnace has been placed in operation at New Mexico State University (NMSU) through the combined efforts and support of the university and Sandia National Laboratories.

All of these facilities fit into one of three general classifications; a solar furnace, a parabolic dish, or a central receiver (power tower) type facility. Basic schematics of each are shown in Figure 1. The solar furnace utilizes a tracking heliostat and a fixed concentrator in a double reflecting mode. The parabolic dish utilizes a single tracking reflector with the test location positioned near the moving focal point. The central receiver design utilizes a tower with tracking heliostats to concentrate the sunlight.

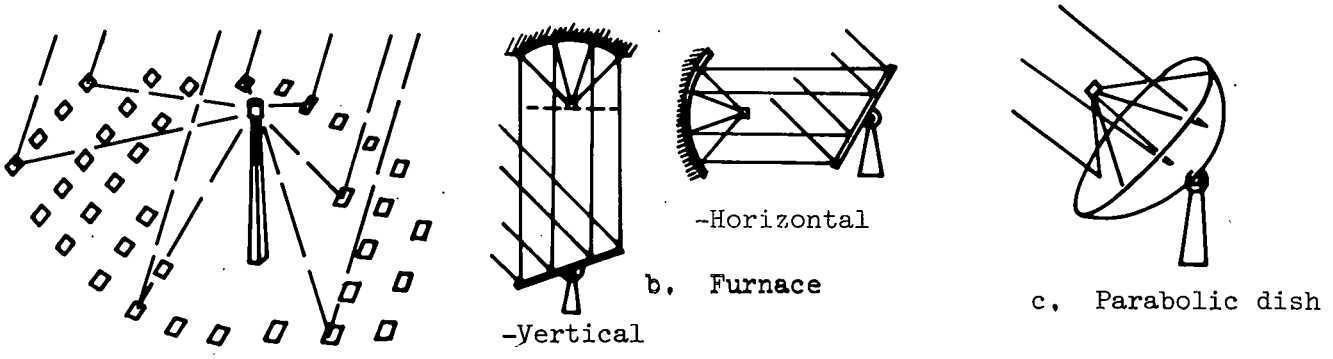


Figure 1. Types of Solar Test Facilities

Both NMSU and WSSF are solar furnaces; the PDTS, recently placed in operation by the Jet Propulsion Laboratory, is a parabolic dish type; while the ACTF operated by Georgia Tech and the CRTF operated by Sandia National Laboratories are central receiver types. Table 1 presents a summary of the basic specifications for these facilities. A wide range of radiation flux densities up to 1300Wcm^2 and a maximum beam power up to the limits imposed by the installed heliostat and dish areas can be provided.

At WSSF, a louvered attenuator and water cooled shutters are used to control the power and shape the energy pulse to an experiment. While the mission of the WSSF has been primarily nuclear weapon thermal effects testing, the facility recently has been utilized for a wide range of solar energy related tests, including coal gasification, calibration of heat flux and photon gage sensors, ore reduction studies, and materials tests.

TABLE 1

APPROXIMATE SPECIFICATIONS FOR SOLAR TEST FACILITIES

Facilities	SANDIA	GEORGIA TECH	WHITE SANDS	JPL
Configuration	Central Receiver	Central Receiver	Horizontal Furnace	Parabolic Dish
Total Thermal Energy, kW	5000	325	30	85
No. of Heliostats	222	550	1	NA
Heliostat or Parabola Size, m	6 X 6	1.1 D	11 X 12	11 D
Total Solar Collecting Area, m^2	8257	532	132	95
Test Area Diameter, m	2-3*	0.5-1.0*	0.08-0.15*	0.09-0.17*
Peak Flux,** W/cm^2	240	125	400	1300
Maximum Temperature,** K	2600	2100	2900	3600

*The first number is area receiving approximately 50% of total energy; second number is area capturing 95% of total energy.
**Small area at center of beam.

The ACTF is composed of a 21.4m tower, 550 mechanically linked mirrors in a collector field and a computerized control and data system. All of the power at the horizontal, downward facing test area is contained in a 1.2m circle with half the power contained in a 0.5m circle. The facility has been successfully used to evaluate both steam and air cooled solar receivers, to test a fluidized bed heat exchanger, and to qualify a reflective concentrator system to be used for exposing soil samples to high energy flux environments.

The PDTF consists of two 11m diameter, 6.6m focal length parabolic concentrators. This facility was recently placed in operation and has been undergoing checkout and calibration. Each dish can provide about $85kW_t$ at the focal plane with peak flux levels near $1300W/cm^2$. An average flux density of $300W/cm^2$ in a circle of about 20cm diameter has been reported. The NMSU furnace was also only recently placed in operation with flux levels of $75W/cm^2$ over a 5cm diameter beam. The facility has been used for solar calibration of flux gages for the CRTF.

The CRTF incorporates many features of a central receiver (power tower) power plant concept yet serves as a flexible test facility. The 61m tower provided 4 test equipment location with cooling fluids and 500 channels of data collection. The glass heliostats are individually controlled to two-axis track the sun in an open loop mode. All or any portion of the heliostat field can be directed onto single or multiple aim points. Operation and maintenance of the heliostats along with variation of reflectivity of the glass surfaces has been documented. Heliostat control electronics (HCE), optical encoders, and drive motors require regular maintenance. Reflectivity measurements show surface dirt and contamination effects but no long term degradation of the silvered mirrors. After 2 years of exposure, cleaned surface reflectivities remain near the original 0.83. Surfaces exposed to the environment degrade to about 0.75 but return to near 0.83 with only natural rain cleaning.

Both heliostats and solar receivers are tested at CRTF. Operation and control of gas cooled receiver operating at about 830^oC and a water/steam cooled receiver operating at 515^oC have been demonstrated. Prototypes of the $10MW_e$ Pilot Plant heliostats were evaluated. Future receiver tests include a molten salt cooled panel, a liquid sodium cooled panel, an air cooled ceramic tubed cavity receiver, and an air cooled cavity with a gas turbine for hybrid solar/fossil fuel operation. Also, prototypes from 5 heliostat designs will under go tracking, pointing, beam quality and beam power measurements.

10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT

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SUMMARY STATUS

Southern California Edison Company (SCE), in a consortium with the Los Angeles Department of Water and Power (LADWP) and the California Energy Commission, has joined the U.S. Department of Energy (DOE) to build and operate the nation's first solar thermal central receiver electric generating facility connected to a utility grid.

This 10-megawatt pilot plant will be located in the Mojave Desert adjacent to SCE's Cool Water Generating Station in Daggett, approximately 12 miles southeast of the city of Barstow, California, and will begin initial operation in 1981. The solar portion of the facility will be owned by DOE and the non-solar portion will be jointly owned 80% by SCE and 20% by LADWP. The total cost of this project is currently estimated at $139.5 million.

A Visitor's Information Center has been constructed in close proximity to the pilot plant. The Center was opened to the public in July 1980. The Center contains exhibits which depict the operation of a solar thermal central receiver power plant, solar energy products and services, and our energy problems, along with alternate energy sources.

Construction at the plant site was initiated in the Fall of 1979. Site clearing, heliostat foundation and receiver foundation work were completed by the summer of 1980. During the Fall of 1980, construction efforts underway include the receiver tower, thermal storage tank, warehouse, control building, major mechanical, major electrical, and heliostat installation. Construction is scheduled for completion in the Fall of 1981 with turbine-roll targeted for December 1981. Following turbine roll, a six month plant acceptance will be performed prior to the beginning of operational testing.

Background - In 1975, the Department of Energy initiated conceptual designs for both a 10-megawatt solar pilot plant and a 100-300 megawatt commercial solar plant. Design teams, with Honeywell, McDonnell Douglas, and Martin Marietta as prime contractors, worked on the entire plant design; Boeing worked only on the design of the mirror modules, called heliostats. All contractors submitted their designs and cost estimates in May 1977. The designs were reviewed intensively by the solar program participants (Electric Power Research Institute, other Federal agencies, and Federal contract laboratories) and a final recommendation was made to the Department of Energy's Division of Solar Technology in August 1977. Subsystems developed by McDonnell Douglas were selected to provide the technical basis for proceeding with the design of the 10-megawatt solar pilot plant.

In August 1978, DOE selected McDonnell Douglas and Martin Marietta companies for Phase I of the collector system (heliostats). Under this phase, each company built three prototype heliostats which were tested at the Central Receiver Test Facility (CRTF) in Albuquerque, New Mexico. Based upon test

results and firm-price bids, a final award for the pilot plant heliostats was made in December 1979 to Martin Marietta.

Also in August 1978, McDonnell Douglas was selected by DOE as the Solar Facilities Design Integrator (SFDI) which includes the design, fabrication, and integration of all solar facility plant subsystems, except the collectors.

Description - The pilot plant will utilize the central-receiver concept of generating electricity from incident solar energy. Sunlight is reflected from tracking mirrors to concentrate on a tower-mounted receiver/boiler that produces steam. The plant design for the collector field calls for 1818 heliostats, with a reflective area of approximately 430 square feet per heliostat.

The heliostat tracking control will require 67-kilowatts of power for operation; when all heliostats are simultaneously moving to the stowed position (face-down, horizontal), the power usage is 328-kilowatts. The signal for vertical and horizontal heliostat tracking control is developed from the calculation of the azimuth and elevation positions for each heliostat as a function of time, mirror position, and target. Azimuth and elevation drive motors then obtain the calculated position using digital encoders for position feedback.

The vertical solar flux density curve impinging on the boiler will be constant over the mid 60% of the panels and taper off to zero flux at both ends. Pointing accuracy is specified as 1.5 mrad.

The collector field will surround the receiver tower with the tower set off-center in the southern portion of the field. The field is an elliptical arrangement about 2600 feet at the major axis and 2300 feet at the minor axis. The total land area for the pilot plant has been set at 130 acres.

The receiver/boiler will be a once-through design with rated steam conditions of 960 degrees F. and 1515 psia. The diameter of the external surface boiler will be 23 feet and the height will be 45 feet. The boiler will consist of twenty-four identical tube panels, each of which will contain seventy 1/2" outside diameter nickel alloy steel tubes. The tower itself will be constructed of steel and elevate the boiler to a height of 235 feet to the bottom of the receiver tubes.

A thermal storage system will be provided to extend the plant's usefulness at night and will be capable of providing 530 degrees F. steam at 400 psia. This will allow the turbine-generator to operate at 70% of rated output (7-megawatts) for approximately 4 hours. The stored energy, excess collected during the day, will be used to heat a high-temperature oil and crushed granite rock system. A thermocline sensible heat storage concept will be employed.

A master control system concept was derived from design features of each of the four Department of Energy conceptual design contractors. The control system will be similar in design to that found in conventional power plants.

The electrical plant generating system will be designed and provided by SCE and LADWP. It will consist of the turbine-generator, cooling tower condenser, feedwater heaters and pumps, associated equipment, and a control room. The turbine will have dual steam inlets to accept steam from either the receiver directly or from the thermal storage system. A wet evaporative cooling tower will be provided for condenser cooling requirements.

Environmental Conditions - The pilot plant is being designed to provide full output (10-megawatts net) for four hours on the worst solar day (December 21) and approximately eight hours on the best solar day (June 21). Any additional steam flow in excess of turbine-generator requirements will be routed to the thermal storage system for use duirng evening and other periods of insufficient sunlight.

The heliostats are being designed to operate in wind up to 35 miles-per-hour, at which point they would be driven to their horizontal stowed position. In the stowed position, the heliostats will be capable of withstanding a 90 mile-per-hour wind.

Currently under investigation is the maintaining of mirror cleaniness as a function of time, weather, and mirror position. Minimal erosion of the mirror surfaces is anticipated based on recent studies and historical data. Also, the stowing of the heliostats during high winds will deter erosion. The glass surface of the heliostats is not expected to be susceptible to problems of chemical erosion and precautionary measures will be taken to protect all metal parts with paint or galvanization.

Cost - Total estimated cost of the pilot plant is approximately $139.5 million. The capital cost contributed by the utility consortium is approximately $21.5 million and by DOE is approximately $118 million.

Test Period - After construction and startup are complete, the pilot plant will be tested for a five-year period to establish operating and maintenance characteristics of the facility. Trained SCE electric utility plant operators will operate and maintain the entire plant throughout the duration of the test period. The experience gained from the test period will influence designs of future solar plants.

CONCLUSIONS

The pilot plant will provide hard experience relating to the cost of designing and constructing a solar thermal central receiver plant. By extrapolating these costs with consideration for economics of scale, production breakthroughs, and technology advances, capital costs of future solar plants can be determined. By combining the projected operating and maintenance costs characterized by the pilot plant's five-year experience record with project capital costs, total solar plant economics can be more closely estimated. Electric utilities and industrial firms requiring process heat will then be able to make better decisions in electing whether to proceed with future solar plants.

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REPOWERING/COGENERATION: ELECTRICITY AND INDUSTRIAL PROCESS HEAT USING CENTRAL RECEIVERS

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In the central receiver program the road to commercialization - the road that will lead to the goal of 1Q of energy by the year 2000 - runs from the 10MWe Pilot Plant at Barstow through cost-shared Repowering and Cogeneration plants to commercialized plants requiring little or no Government incentives. I want to tell you the status and plans of the Repowering and Cogeneration segments of that road.

"Repowering" is the term given to the augmentation with a central receiver system of an existing oil or gas fired boiler used either for process heat or electric power generation. Incentive for this application is provided by the Power Plant and Industrial Fuel Use Act of 1978, which prohibits the use of oil and gas in certain new electric plants and industrial boilers, and encourages existing facilities to shift to alternate fuel sources. For a repowering plant, the required investment is much lower than for a stand-alone solar plant, since credit can be taken for the EPGS machinery already existing in the plant.

Heliostats are the key cost item in the central receiver system and are therefore the area where cost reduction efforts are being concentrated. It is estimated that for central receiver stand-alone systems to be competitive with alternative systems in the late 1980's, heliostat costs have to be reduced to about $\$72/m^2$. But a repowered system, which can take the cost advantage of an existing EPGS, can be competitive at a heliostat cost of about $\$150/m^2$. Our studies on heliostat cost reduction learning curves indicate that this cost of $\$150/m^2$ can be met with cumulative production of only 20,000 heliostats. A demand for 20,000 heliostats can be met by a small number of Repowered plants (on the order of three to six plants depending on installed capacities, capacity factors, etc.). This is of key significance in DOE's decision to adopt the Repowering path to commercialization. Based upon the results of studies by Public Service Co. of New Mexico, Mitre Corporation, SERI, Sandia Laboratories Livermore, and others, DOE solicited proposals from industry in March 1979 for site specific conceptual design studies for demonstrations of repowering of electric power plants or industrial retrofit for process heat plants. 12 studies were funded by DOE and a 13th was independently funded, and were conducted during the period September 1979 to July 1980. Seven of these studies were for electric power plants and six were for various process heat applications. Reports of these studies are now publicly available through NTIS.

These design studies showed excellent technical promise and indicated widespread user support. Using these studies as a data base, DOE is preparing to issue * a Program Opportunity Notice for proposals to design and construct up to four repowered/retrofit plants on a cost-sharing basis. These plants would be on-line by or

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* By the time of this Conference, the PON may have already been issued.

before the 1985-1986 time period. In order to provide a broad base of information and experience, it is expected that the selections will cover a wide variety of technologies and applications, e.g., electric and process heat applications; different working fluids and receiver types, different storage options.

A companion and working partner to Repowering on the path to central receiver commercialization is Cogeneration. Cogeneration refers to systems that provide both electrical (or mechanical) energy and thermal energy; the thermal energy used for industrial process heat or for space conditioning and hot water. Solar cogeneration can take advantage of the regulatory exemptions and incentives provided to cogeneration facilities under the Public Utilities Regulatory Policy Act and other sections of the National Energy Act of 1978. Cogeneration optimizes the production of energy from a fuel efficiency point of view and, for example, can increase the economic attractiveness of solar central receiver plants by reducing the size of the heliostat installation which, as said before, accounts for a large share of solar plant costs.

As a result of a competitive solicitation, seven Cogeneration conceptual design studies are now underway, as shown below:

Team Principals	Thermal Heat Application (together with electricity)	Site
Bechtel/Amfac	Sugar Mill	Maui, HI
Black & Veatch/Central Telephone & Utilities	Natural gas processing	Liberal, Kansas
Exxon/PG&E	Enhanced oil recovery	Bakersfield, CA
GE/Texas Gulf	Sulfur mining	Fort Stockton, TX
Gibbs & Hill/Phelps Dodge	Copper smelting	Playa, NM
McDonnell Douglas/ Department of Army	Space conditioning	Fort Hood, TX
Westinghouse/USAF	Space conditioning	Robins AFB, GA

These studies will provide data to DOE, solar equipment suppliers, and plant users on potential industrial applications for central receiver technology. The projects defined by these studies will become candidates for cost-shared demonstrations in future phases of the program.

Repowering and Cogeneration represent a near term, relatively low cost approach to development of a significant alternative energy source. The central receiver concept lends itself to rapid integration into existing U.S. energy structures with minimal environmental effect. We believe that the present program plan, including Barstow plant operation and the proposed construction projects, will demonstrate the technology, provide utility and industrial user acceptance, and establish the necessary competitive industrial base to achieve the goal of commercialization.

SOLAR HYBRID FULL SYSTEM EXPERIMENT

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Early EPRI funded studies have shown the potential benefits of Brayton-cycle concepts used in a solar-fossil hybrid mode of operation. A central receiver power plant design concept was developed. Critical heat exchanger material tests were conducted which proved 30 year cyclic life capability in the anticipated thermal environment. A test program was prepared which would progress in an orderly manner from a Bench Model Receiver through an experimental plant, to a commercial size plant. The recommendations of that study were implemented in July, 1976, when Boeing Engineering and Construction was awarded a contract for design, fabrication, and test of a 1MW$_t$ Bench Model Solar Receiver. Testing was completed at the DOE Central Receiver Test Facility in March, 1979. The program proved the feasibility of solar energy conversion in a cavity-type receiver; and provided one major tested hardware component of a solar electric power system, the gas-cooled metal tube receiver.

The next step in the progression to commercial utilization of solar power systems is the design and construction of an experimental plant where all elements of the power generation system are assembled and operated as a single unit. This will provide an opportunity to address the major design, integration, performance, operational, and test issues for a complete solar plant. It will also provide a complete operating system on which utility personnel can obtain experience and training. EPRI has initiated this activity with the award to Boeing Engineering and Construction of contract RP 1509-1 to design, assemble, and operate a Solar-Hybrid Full System Experiment. Maximum utilization of existing components is a key goal. Thus, the 1MW$_t$ Bench Model Receiver and the tower and heliostat field of the CRTF will be employed. Additional components include an industrial gas turbine/generator and a parallel arrangement trim combustor employing fossil-fuel to supplement solar operation. The major elements of the Full System Experiment are shown in figure 1.

Because of the importance of this project to future utility applications of solar-thermal systems, the work will be performed in close cooperation with a group of participating utilities. A "users group" of utilities will be solicited, organized, and coordinated by the lead utility, Public Service Company of New Mexico. The users group will identify critical items to be considered in the experiment and lend guidance relative to design, operation, and maintenance so as to be consistent with utility practices.

Phase I, the design/analysis task, started on July 1, 1980, and is scheduled for completion at the end of February 1981. Phase II is a twelve-month effort to perform the necessary fabrication and assembly of components. Phase III is also a twelve-month effort to conduct the system checkout, experimental and solar operating portions of the test.

Boeing Engineering and Construction has selected two subcontractors for performance of key tasks in the program. Solar Turbines International (STI) will conduct the turbine selection trades, select a control concept and design a fossil-fuel trim combustor. Gibbs & Hill Consulting Engineers complements the program with their background in engineering and construction of gas turbine and combined cycle power plants. Their task is to establish criteria for selection of utility users groups.

)ther program participants include the DOE, providing the Central Receiver Test 'acility, and Sandia Laboratories, the operator of the Test Facility.

An early study made possible the screening of many turbine candidates to the two selected for evaluation in this program, the Solar Spartan and Titan. A field of 29 turbines was reduced initially by determining their availability as generator drives and as current manufacture industrial units; and availability of technical support in the U.S.A. Further screening was done by comparing the turbine characteristics "match" with the previously tested solar receiver. Electric outputs on the order of 70KW$_e$ in the "solar-only" mode are possible.

Three different types of solar-electric power utilization are envisioned for the experiment. These include: connection to an active electric power grid, connection to an isolated CRTF power bus serving various equipment in the facility, and connection to a resistive dummy load bank. An electric power distribution device may be included as part of the Full System Experiment to enable remote selection of these various loads from the control building at CRTF.

The experiment control system incorporates two computers to provide the required control and operational flexibility for system test, demonstration and training. A master control computer will establish desired operating points, request changes in the collector field, monitor system operation, provide event and test summary reports, and display system status to the operator. A microprocessor-base turbine/combustor controller will handle the tasks of actual data acquisition and hardware control. Automatic control of the collector field is desired to demonstrate controlled system operation. The CRTF collector control computer can be connected to the experiment master control computer. This will allow the master control computer to request the addition or removal of heliostats.

Summary EPRI has initiated the Solar-Hybrid Full System Experiment program to provide an operating system for use in evaluating different operating strategies and techniques; on which subsystem and full system operating experience can be obtained; and where utility personnel can be introduced to the complete solar-thermal power generation process by means of performing full system experiments.

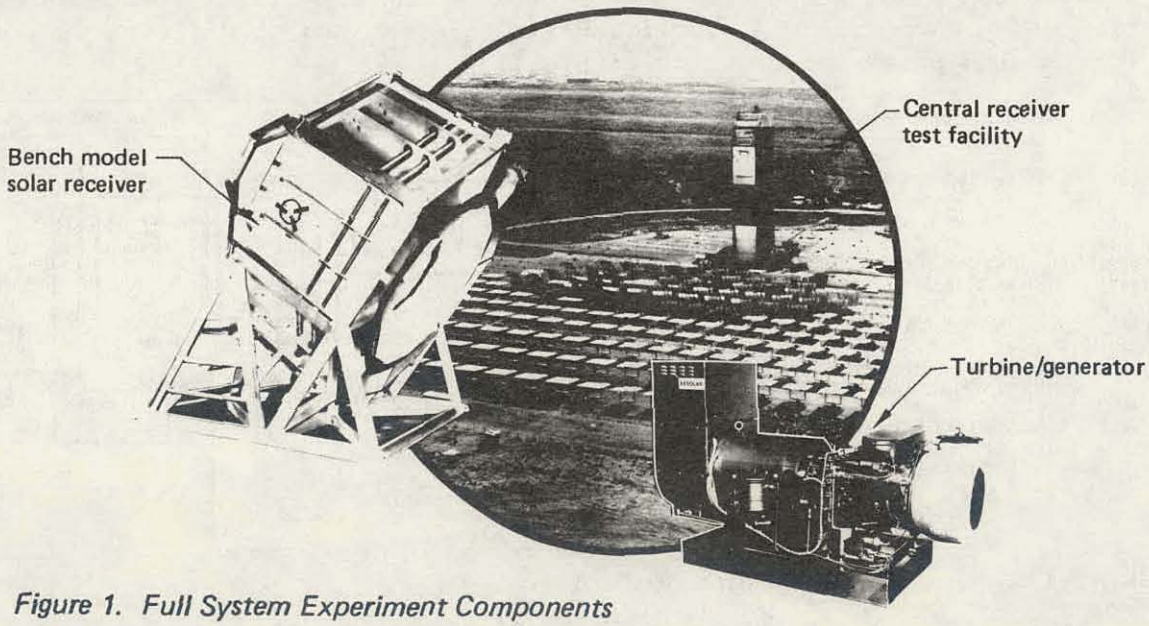


Figure 1. Full System Experiment Components

INTERNATIONAL ENERGY AGENCY PROJECTS IN SPAIN*

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The International Energy Agency (IEA), established as an autonomous body within the Organization for Economic Cooperation and Development (OECD), undertakes activities such as the establishment and conduct of cooperative energy research, development and demonstration projects of alternative energy sources. One of these demonstration projects is the Small Solar Power Systems (SSPS) Project being built in the Province of Almeria, Spain. The SSPS Project consists of a Central Receiver System (CRS) plant and a Distributed Collector System (DCS) plant located adjacent to each other and with similar 500 KWe output. Project funding is from contributions by the nine participating IEA member countries of Austria, Belgium, Germany, Greece, Italy, Spain, Sweden, Switzerland and the United States of America. Supervision authority is vested exclusively with the SSPS Executive Committee, in which each member country has one vote, and is managed on a day-to-day basis by Deutsche Forschungs-Und Versuchsanstalt Fur Luft-Und Raumfahrt (DFVLR), Germany, acting as Operating Agent on behalf of the Executive Committee.

Objectives of the SSPS project are to: (1) demonstrate, within about two years from 1979, the construction of CRS and DCS plants emphasizing available technology, minimizing research and development, and provide for design flexibility (scaling potential, operational modes, geographically dispersed applications), (2) gain, over a substantial two year period of test and operations, experience with such plants relative to operational reliability, investment, and running costs, and (3) assess further technical and economical developments and applications of such plants. The basic contract for the construction of the DCS plant is with a consortium of three companies; Acurex, United States, Maschinenfabrik Augsburg - Nurnberg (MAN), Germany, and Technica Reunidas (TR), Spain. Ansaldo, Italy, has a supplemental contract to provide additional collectors and an oil/solid thermal storage system. Much of the hardware for the DCS plant has been subcontracted by the consortium to companies in other participating countries. A simplified flow diagram and significant design features for the DCS plant are shown in Figure 1.

Significant Design Features

Collector Fields	2688 m^2 MAN Double-axis Tracking 2674 m^2 Acurex Single-axis Tracking 500 m^2 Ansaldo Double-axis Tracking
Collector Temperatures (input/output)	MAN and Acurex 225/295°C Ansaldo 240/315°C
Heat Transfer Fluid	Thermal Oil
Storage	.8 MWHe Oil Thermocline .7 MWHe Oil/Solid Thermocline
Power Conversion	Stal-Laval Steam Turbine
Performance	500 KWe net output
Design Life	10 years

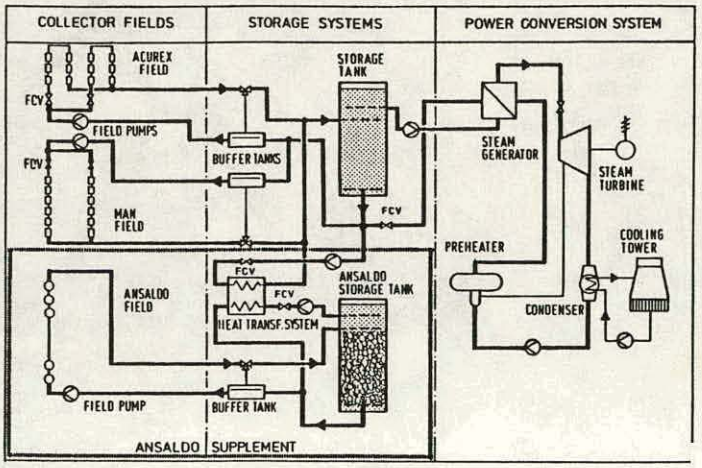


Figure 1 Simplified Flow Diagram of the DCS Plant and Significant Design Features

*This work is supported by the U.S. Department of Energy.

There are three basic contracts for the CRS plant. Martin Marietta, United States, is supplying the heliostat field and associated controls, Societe Anonyme Internationale de Telecommunications, Belgium, is supplying the data acquisition system, and Interatom, Germany, is supplying the balance of the plant. Both Martin Marietta and Interatom are subcontracting to companies in other participating countries for hardware and services. A simplified flow diagram and significant design features for the CRS plant are shown in Figure 2.

Significant Design Features	
Heliostats	3715 m^2 total reflective area, Barstow type
Receiver	Cavity type with octagonal aperture of 9.7 m^2 270°C inlet/530°C outlet
Heat Transfer Fluid	Sodium
Storage	1 MWHe Two Sodium Tanks
Power Conversion	Spilling Steam Motor
Performance	517 KWe net output
Design Life	10 years

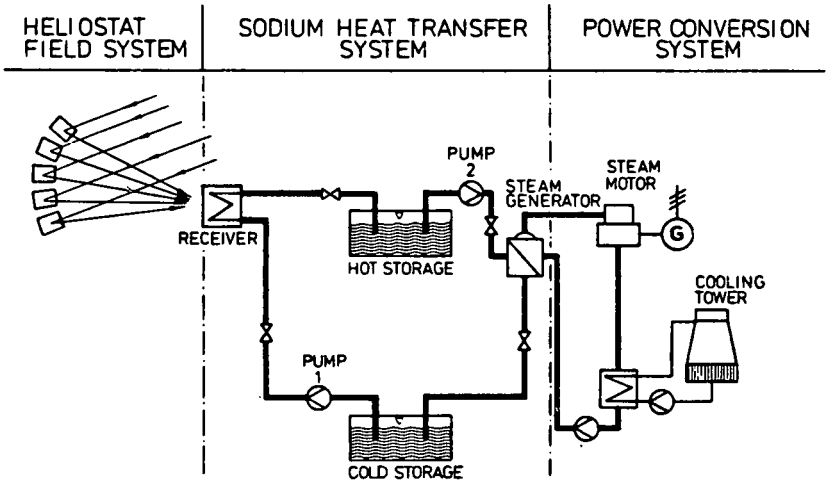


Figure 2 Simplified Flow Diagram at the CRS Plant and Significant Design Features

It is currently planned that the Italian companies, Snamprogetti and Franco Tosi, will provide the CRS plant an advance sodium receiver in CY 1982. This advance receiver will be an external type with a peak design solar incident flux of over 1.0 MW/m^2. Site design and construction for both the DCS and CRS plants are being done by Spanish companies INITEC and Laing, respectively. Acceptance testing of the CRS plant is scheduled to be completed in July 1981 and for the DCS plant in August 1981.

After both plants have been accepted by the Operating Agent (O.A.), on behalf of the Executive Committee, the SSPS project will begin a Test and Operations (T&O) phase lasting about two years. This phase of the project is planned to be separated into two functions: (1) operations and maintenance which will provide the day-to-day operations and maintenance of each plant and (2) test and evaluation which will plan, execute tests, guide operations, and evaluate plant performance. The Executive Committee has decided to have a T&O Advisory Board with one member and alternate from each participating country to provide program planning review and support. Operation and maintenance are planned to be provided by a service contract from the O.A. Test and evaluation are planned to be done by an international team under the guidance of the O.A. This international team may be composed of nominated experts from participating countries and would be assigned to the SSPS project for six months to a year. Preferably these experts would come from research institutes, utilities, manufacturing and consulting firms. Financial support for the international team has not been decided to date but it is desirable that their funding not be from the SSPS project budget.

In conclusion, the CRS and DCS International Energy Agency projects being built in Spain will complete their two year construction phase in July/August, 1981. Planning for the subsequent two years of test and operations phase is in the process of being finalized. It is planned that interested experts in the SSPS participating countries will have the opportunity to be actively involved in the SSPS test and operations phase of the project.

SOLAR-POWERED IRRIGATION FACILITY DEMONSTRATION
COOLIDGE, ARIZONA

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By the year 2000 the national energy goal calls for 0.4 quads of electrical power to be supplied by solar systems which are engineered to efficiently take advantage of the sun's resources.

Several organizations, both private industries and government agencies, are developing systems that will be ready to produce reliable power in the next few years. Many of them will draw on data being produced by a 150 kWe system operating right now on a farm near Coolidge, Arizona.

This facility, in operation since September 1979, is sponsored by the Department of Energy and engineered and constructed by Acurex Corporation of Mountain View, California. It provides electricity to drive irrigation pumps that bring water from wells 380 feet deep.

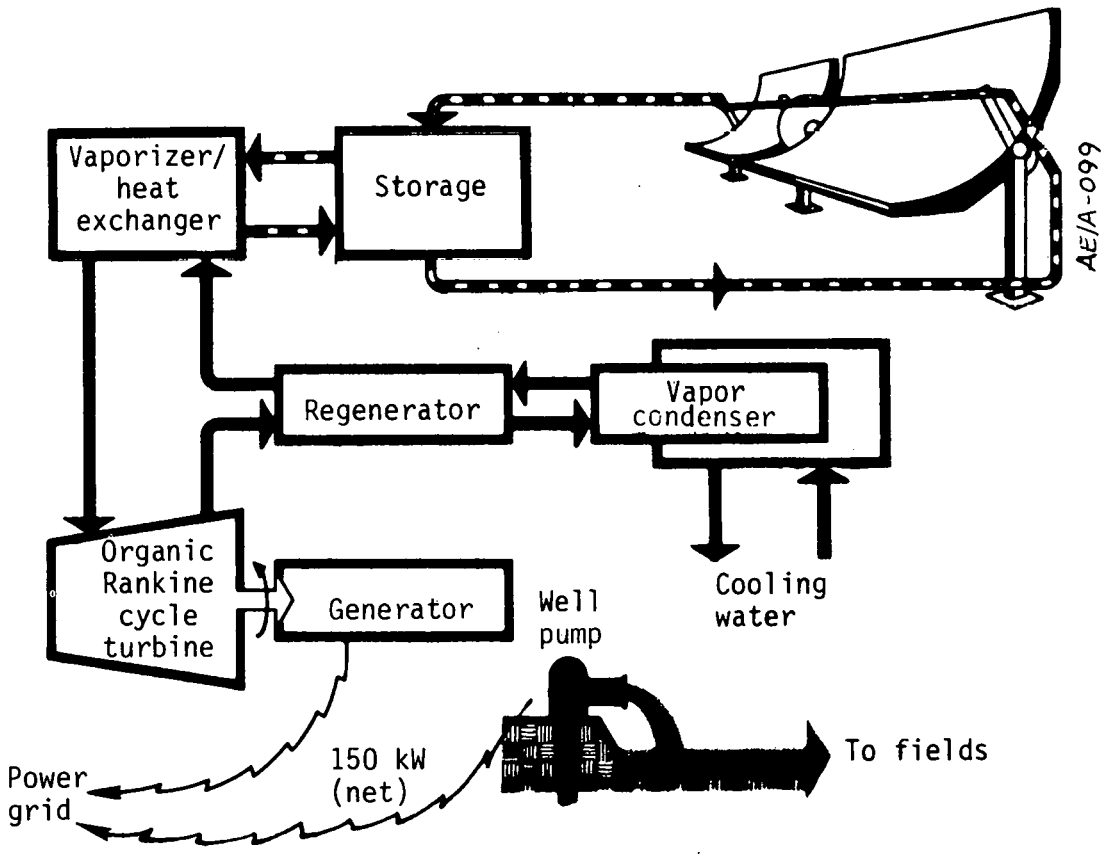


Figure 1. 150 kW Solar-Powered Irrigation Facility Schematic

Solar energy at the Coolidge site is collected by a field comprising 23,040 ft^2 of Acurex Model 3001 Concentrating Collectors, and is converted into electrical energy by a Sundstrand Organic Rankine Cycle (ORC) unit. A simplified version of the process is shown in Figure 1. During steady-state, warm heat transfer oil (Caloria HT-43) taken from the bottom of a 30,000 gal thermal storage tank circulates through the collectors and returns to the top of the tank as hot oil. From there, via an independent loop, the hot oil passes through a heat exchanger where the working fluid (toluene) for the ORC unit is vaporized, and the cooler oil returns to the bottom of the storage tank. Within the ORC unit, the toluene vapors are expanded through a turbine which in turn drives a generator to produce electricity. The toluene exhaust vapors are subsequently condensed and the cycle is repeated. The electricity generated is fed into the utility grid and credit is received for its value. The irrigation pumps draw power directly from the grid. A thermally full storage tank can provide approximately 6 hours of power generation.

Detailed design, procurement, construction, and startup of this facility occurred over a 2-year period beginning in September 1977. On 1 October 1979 the responsibility for operating the system was turned over to the Department of Energy's technical advisor, Sandia Laboratories, and the University of Arizona. By the end of June 1980, the system has generated 66,100 kWh of electricity, the ORC unit has operated for 412 hours, and the collector subsystem has operated 86 percent of the available insolation hours. Within the last 3 months, as the system has shaken-down, performance has improved markedly; 53,730 kWh of electricity were produced, 309 hours were logged on the ORC unit, and the collectors operated 94 percent of the available insolation hours.

The installation at Coolidge is currently the largest operating solar-thermal power plant in the world. Unquestionably, it has demonstrated that reliable electric power can be generated from solar-thermal energy. Future solar-thermal electric systems can help the nation achieve its goal of domestic production of electricity. Future systems, too, will become more cost effective through improvements in technology, standardization of designs, and economies that result from larger scale units and greater production quantities.

THE SOLAR TOTAL ENERGY PROJECT AT SHENANDOAH, GEORGIA

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INTRODUCTION - The Department of Energy has completed the design of a Solar Total Energy experiment at Shenandoah, Georgia. The Solar Total Energy System (STES) will have the capacity to supply about 50% of the electrical and thermal requirements of a knitwear plant at the Shenandoah site. The system will provide 400 kilowatts electrical and 3.0 megawatts thermal peak.

The STES is a cascaded total energy system configuration. Energy is provided by parabolic dish collectors. The system is designed for interconnected operation on the Georgia Power system. It will also have capability for stand-alone operation.

Seven meter diameter parabolic dish solar collectors with cavity receivers will be used. The collectors, designed by General Electric, are fabricated from die stamped aluminum petals. The collector efficiency is about 65%. The 114 collectors will be arrayed in a diamond-shaped pattern on a 5 acre collector field. The collector field at Shenandoah will provide about 11×10^9 BTU annually.

Operating with inlet conditions of 382°C (720°F) and 4.8×10^6 Pa (700 psig), 400 KW of electricity can be generated. In the peak shaving mode of system operation, Georgia Power will provide a base lead of 100 KW. 35% of the electrical load and 60% of the process steam requirements of the Bleyle Knitwear plant will be satisfied by solar energy.

Heating and cooling for the knitwear plant is provided by use of exhaust energy from the turbine. On an annual basis, 80% of the site cooling and all of the heating load are provided by solar energy.

The control system uses a central minicomputer with distributed microprocessors to control the STES operations.

SOLAR COLLECTORS (SC) - The solar collector is a 7-meter parabolic dish with a cavity receiver. Reflected solar energy is focused onto a coil of stainless steel tubing within the receivers.

The total field temperature rise to 400°C (750°F) from 260°C (500°F) occurs in each receiver. The heat transfer fluid in the receiver is Syltherm ™ 800.

The reflector assembly consists of 21 die stamped aluminum petals attached to a central hub. A highly reflective specular surface, FEK 244, acrylic film is laminated to the aluminum sheet prior to forming.

The collectors track the sun by means of linear actuators and lever arms in both the polar ($\pm$ 90°) and declination ($\pm$ 23.5°) axes. A two-stage sun tracking technique is employed; course tracking of the sun ($\pm$ 1°) is computer controlled; and fine tracking of the sun ($\pm$ 1/4°) is obtained by nulling the output of optical sensors which monitor the sun's reflected image.

HIGH-TEMPERATURE THERMAL ENERGY STORAGE SUBSYSTEM - The system will not initially incorporate high temperature storage because of cost. A thermocline Syltherm™ 800 heat transfer fluid buffer storage of 5.3×10^9 joules (5×10^6 BTU) is included to cover transient conditions.

A trickle oil storage concept was designed by General Electric. In this storage system, the heat transfer fluid is introduced at the top of the tank by a manifold and allowed to trickle through an iron ore storage media. In both the charging mode and discharging mode, energy is transferred between the storage media and a thin film of the heat transfer fluid. Storage may be incorporated in the future.

POWER CONVERSION SUBSYSTEM (PCS) - Major elements of the PCS are a steam generator with preheat and superheat sections, and the MTI turbine generator make-up demineralizer, deaerator, required pumps and local controls.

The recirculating fluid from the collector field can deliver, 3×10^6 watts (10 million BTU/hr) to the steam generator and provide up to 10,500 lb/hr superheated steam to the steam turbine. In the event of turbine outage, the steam generator can provide saturated steam at 7.6×10^5 Pa (110 psi) for process and thermal use.

The turbine generator produces 480 volts, 3 phase, electrical power in the range of 150-400 KW (e). The steam turbine is a high specific speed, high efficiency design. Average stage efficiency is 69%. Extraction of steam from the turbine provides steam for the Bleyle plant and deaerator heating at 193°C (379°F), 8×10^5 Pa (115 psia).

THERMAL UTILIZATION SUBSYSTEM (TUS) - The TUS consists of a 500-ton absorption air conditioner fired with turbine exhaust 110°C (230°F) and cooling towers for heat rejection from the absorption air conditioner and excess energy from the PCS.

CONTROLS AND INSTRUMENTATION SUBSYSTEM (CAIS) - The CAIS initiates, regulates and terminates collector tracking, energy storage, power generation and thermal utilization for heating and cooling of the Bleyle plant and the STES mechanical building.

The CAIS consists of a central control console, a central minicomputer and two remote microprocessor control units. The control system has the flexibility to be operated in a manual or automatic mode, and permits the operator to monitor or control the system functions from the control panel. Color graphic cathode ray terminals are employed for data display. Data archiving is performed with magnetic storage tapes and in hard copy form on the computer line printer. The remote microprocessors are programmable from the central minicomputer to allow a high degree of system control and versatility.

ACKNOWLEDGMENT - The information presented is the result of efforts by the U. S. Department of Energy. Georgia Power Company, through Cooperative Agreement with DOE, participates in the project by providing the site and cost shared services. General Electric, under DOE contract, provided the initial system design. Sandia National Laboratories provides technical and management support to the DOE.

THE SMALL COMMUNITY SOLAR THERMAL POWER EXPERIMENT

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The Department of Energy's Solar Thermal Program objective is to assist industry and users in establishing a viable energy alternative based on solar thermal power system technologies. One element of the DOE solar thermal program deals specifically with the development and utilization of a two-axis tracking parabolic dish to provide thermal energy for conversion to electricity or to be used in process heat applications. DOE, through an agreement with NASA, has selected the Jet Propulsion Laboratory (JPL) as the technical manager of the Parabolic Dish Program.

An early recognition that parabolic dishes were ideally suited for small electric power applications led to their selection as the most viable candidate to meet the electric energy needs of the small communities. This paper describes the program that has been established in this area and the first experimental power plant for the small community application.

PARABOLIC DISHES FOR SMALL ELECTRIC APPLICATIONS

Parabolic dish concentrators are two-axis tracking devices capable of collecting a higher percentage of the available insolation than any other technology. In addition, the high optical concentration ratio of the dish enables high temperatures to be achieved leading to high conversion efficiencies and the potential for low cost power if these systems are produced in large quantities. Figure 1 shows the major components of a parabolic dish module.

Two fundamental attributes of parabolic dish technology are its significant potential for low cost energy because of the unusually high system performance and its inherent modularity. The first provides a promise for eventual large-scale deployment of these systems and, thus, a national energy impact. The second permits widespread application in near-term, diverse markets giving an early incentive to manufacturers to produce these systems.

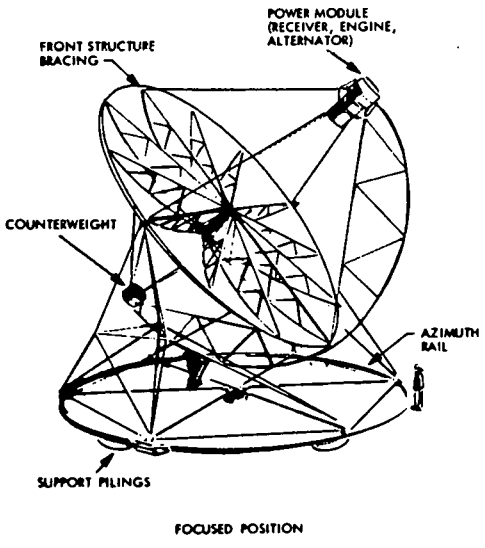


Fig. 1 Parabolic Dish Module

THE SMALL COMMUNITY PROGRAM: A FOCAL POINT FOR THE PARABOLIC DISH PROGRAM

The Small Community Solar Program is designed to meet the needs of a diverse small community energy market. Dispersed power plants, frequently found in small communities are especially susceptible to the rising cost of fuel and capital equipment. These rising costs have forced many communities to combine resources to finance large central stations. Other communities are isolated and must pay higher prices for petroleum products

due to additional transportation costs and low volume buying. The parabolic dish system offers an alternative whereby these communities can again produce and control their own power. Figure 2 illustrates typical results in terms of annual new capacity needed in 1990 for several near term small community markets. An integral part of the program is the placement of engineering experiments in selected sectors to establish feasibility of the technology at the system level and to test the appropriateness of the application and technology match. Several such experiments have been initiated and the one most explicity addressing the small municipal community market is the Small Community Solar Thermal Power Experiment.

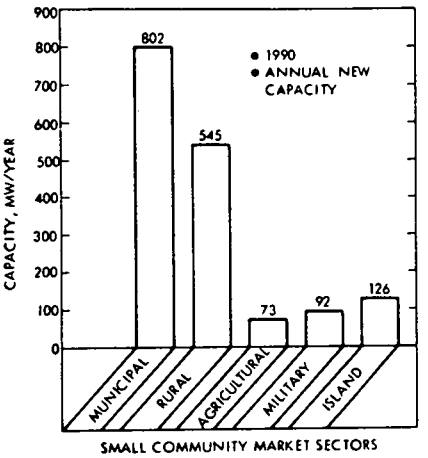


Fig. 2

THE SMALL COMMUNITY SOLAR THERMAL POWER EXPERIMENT

The first solar thermal power plant specifically designed as an alternate source of electric energy for small communities in this country is now in its second phase of development. As a result of Phase I concept definition studies, a decision was made to pursue a parabolic dish system using distributed generation. The plant will produce 1 MWe at peak insolation conditions. A typical layout is depicted in Figure 3. Generally, the technology selected for the Small Community Solar Thermal Power Experiment (SCSE) is considered near-term with regard to development and availability. The concentrator is a parabolic dish (Fig. 1) developed by the General Electric Company. It is a first generation concentrator using a reflective film bonded to reinforced plastic substrate. The receiver is a new design being developed by Ford Aerospace and Communications Corp., the systems contractor. The power conversion subsystem will employ an organic Rankine engine being developed by Barber-Nichols Engineering Co. The Phase II effort will include design, development, and verification testing. This is a two-year activity that will provide a system design including the plant control system and other balance of plant considerations. Verification testing at the module level will be at the JPL Edwards AFB Parabolic Dish Test Site.

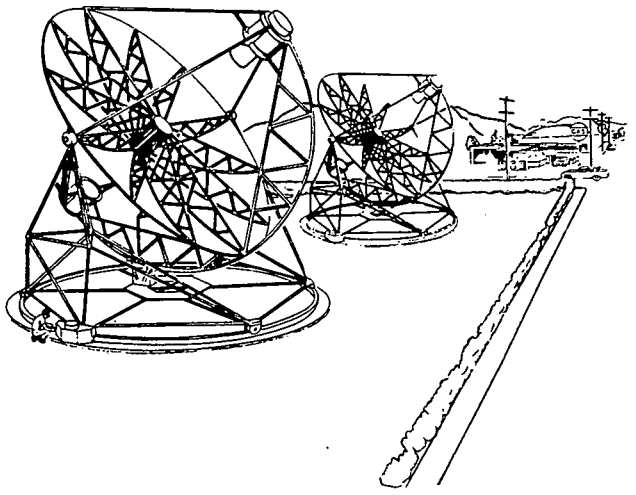


Fig. 3 Small Community Experiment

Site selection for the experiment was initiated earlier this year by DOE/ALO. An enthusiastic response to the PRDA was received from 44 communities. One of these will be selected as the site for the experiment. Five other top contenders will be given awards to provide site specific data in support of future DOE activities.

OPERATION AND DESIGN OF SELECTED INDUSTRIAL PROCESS HEAT FIELD TESTS

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The U.S. Department of Energy has funded a series of field tests since 1977 to gain operational experience in the application of solar energy to industrial process heat requirements. To date, 26 studies or actual installations have been funded utilizing technologies ranging from flat plates to line-focus concentrators (a series of six similar project studies on central receiver industrial systems is not discussed here). The types of solar systems include hot air, hot water, and steam production applied to a broad spectrum of industrial processes.

The early hot air and hot water projects, as well as two steam projects, are operational and providing important feedback to the design of current systems. The operational systems on the whole have shown good reliability and lower than predicted system thermal efficiency. An examination of the causes points to a need for better design to reduce thermal and parasitic losses, and for improvement of the solar/industrial process interface. Failure of routine nonsolar components (pumps, valves, controls) has been a continuing problem. Operational data from later field tests will be available for a number of projects in 1981. In order to focus on specific operational experience and design approaches, this paper discusses four selected projects:

L&P Foods:[1] This system consists of 1950 m^2 (21,000 ft^2) of air collectors that supply hot air to a 396 m^3 (14,000 ft^3) storage bin and 1 of 14 dehydration tunnels for raisins and prunes. A 3.7-m (12-ft) diameter heat recovery wheel transfers heat from the tunnel exhaust to the fresh-air collector inlet. During the drying season, prunes and raisins are stacked on trays and move through the gas-fired dehydration tunnels with a residence time of 24 hours.

As is typical of food-drying operations, the plant operation is seasonal, limiting the cost effectiveness of a solar system. In this case the typical drying season is from August to February. Single-glazed (Lexan) flat-plate collectors for this project were constructed on site at a cost of \$263/m^2 (\$24.50/ft^2). The heat recovery unit, installed as part of the solar system retrofit, supplies about 2-1/2 times more energy to the air than the solar system at a much lower cost, pointing out the economy of routine energy conservation techniques.

Only minor operational problems exist at the site. The Lexan glazings have visibly yellowed, but collector array efficiency has not markedly decreased. Thermal system efficiency is about 25%, with an 18% net system efficiency after deducting the thermal equivalent of the high parasitic power requirements to circulate air through the system.

Johnson & Johnson:[2] Low pressure steam is generated by a solar system employing 1070 m^2 (11,520 ft^2) of Acurex Model 3001 parabolic trough collectors in which pressurized water circulates directly through the collectors, reaching temperatures as high as 216°C (420°F) before being throttled into a flash boiler. Water in the boiler flashes to steam to supply the plant steam main at 125 psi. This simple plant interface typifies solar steam production. For this application, process steam is used in the manufacture of surgical dressings.

Initial system checkout began in November 1979, with normal operation commencing in January 1980. System availability has been excellent (97% through June 1980). Minor early operational problems resulted from difficulties such as flow switch and control pressure gage failures, and improper sizing of collector flex hoses. Performance of the system has been promising with net system efficiencies on the order of 35% under good insolation conditions. System energy delivery is being compared to prediction for actual insolation and weather conditions in order to gain a more complete understanding of system performance. Thermal line losses are higher than design values, and the parasitic losses inherent in a flash system are significant.

Ore-Ida:[2] This application, currently under construction, utilizes solar-produced 300 psia steam at 214°C (417°F) to heat oil, through a heat exchanger, to fry potatoes. Line-focus Suntec parabolic troughs in a 883 m^2 (9500 ft^2) array generate hot water at 249°C (480°F) and 600 psia, which is then flashed to operating conditions in a flash tank. The steam from the flash tank interfaces with the plant process steam through a simple connection into the steam main.

The conceptual design reviewed three methods of producing the steam. These included use of a heat transfer fluid and unfired steam generator, a pressurized water system with an unfired steam generator, and a pressurized water flash steam system. Silicone oil was chosen as the heat transfer fluid in the first alternative. FDA regulations, however, preclude the use of silicone oil to produce process steam without an intermediate unfired steam generator, adding to the cost and complexity of the system. Given this constraint, the two pressurized water systems had an edge on technical and cost merits, with the flash system being chosen as marginally superior in this particular case. In general, FDA and USDA regulations warrant careful attention in the introduction of solar process heat into the food industry.

The original design for this project called for a roof-mounted collector field. Subsequent analysis determined that, in fact, the roof was inadequate to withstand the collector loading and a ground-mounted array was more attractive than attempting to strengthen the existing roof. In contrast to the selection of the flash steam system in this and the J&J project, other conceptual designs for IPH steam systems have also chosen to generate steam in an unfired boiler heated by a heat transfer fluid which passes directly through the collector field.

Nestle' Enterprises:[3] This hot water system is being designed primarily for fruit juice and nectar pasteurization at 99°C (210°F). Secondary uses of the collected energy are boiler preheat and cleanup operations. Pasteurization is normally accomplished in an APV pasteurizer with steam-heated hot water; with solar, the hot water supplied via hot water storage (75,000 gal.) will be connected directly to the APV water loop.

Located in Puerto Rico, this site is characterized by high ambient temperature, good insolation, and a moderately high diffuse/direct insolation ratio. Both evacuated tube and parabolic trough collectors appeared suitable for this application on the basis of the cost of delivered energy. However, the strong interest of the industrial partner in the use of low-maintenance nontracking collectors at this more remote location led to the recommendation of General Electric TC-100 collectors for the 4645 m^2 (50,000 ft^2) array. The large hot water storage system in this design is typical of food processing solar system requirements. An unusual feature, however, is that the storage water level will drop slowly during the week due to the direct use of storage water for end-of-day cleanup. The tank will be replenished and heated over the weekend during plant shutdown. The solar system is designed to provide almost 60% of the annual plant needs, an important contribution in a locale fully dependent on imported oil.

For low-temperature applications such as this, it is apparent that a variety of collector technologies—parabolic trough, Fresnel lens, evacuated tube, flat plate—should be considered in the temperature range from 140°F to 200°F, and numerous competing and important design issues must be carefully weighed in the light of specific project requirements.

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SALTON SEA PROJECT

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The Salton Sea is a large inland body of salt water located in Southern California. The Salton Sea Solar Pond Project proposes the construction of nonconvecting, salinity-gradient solar ponds in the Salton Sea to provide thermal energy for the generation of commercial electric power. An added benefit will be the reduction of the salinity in the Sea and the preservation of its established ecosystem. Phase 1 studies are now being conducted to determine the technical, economic, and environmental feasibility of the concept.

The study is sponsored by the Department of Energy, the Department of Defense, the State of California, Southern California Edison Company and Ormat Turbines Ltd. Participants in the study include the Southern California Edison Company, Jet Propulsion Laboratory, Ormat Turbines Ltd. and WESTEC Services, Inc. Phase 1 will be completed in April of 1981. Phase 2 will involve construction and testing of a 5 MWe prototype and phase 3 calls for a commercialized power plant which involves the sequential construction of modular units to achieve a base load plant capacity of 600 MWe. The optimum module size will be determined during the phase 1 studies and is expected to be in the range of 20 MWe to 50 MWe.

A solar pond combines solar energy collection and thermal energy storage. Solar ponds can deliver thermal energy day and night, winter and summer. Delivery temperatures of 90°C have been demonstrated.

There are three zones in a nonconvecting, salinity-gradient solar pond, an upper convective zone, a middle nonconvective zone and a lower convective or storage zone. The concentration of salt and the corresponding brine density is maintained at a low level in the upper convective zone and at a higher level in the lower storage zone. In the nonconvective or middle zone the salt concentration and density increase with depth. Thus the resulting density profile stabilizes the zone and prevents internal convection.

The key to the operation of the solar pond is the center nonconvecting zone. This zone allows the transmission of a portion of solar radiation into the lower zone while insulating against the upward conduction of thermal energy. A typical nonconvecting zone is about 1.2 meters thick and provides an insulative value equivalent to about eight cm of foam.

A solar pond can serve as both the thermal source and sink for a Rankine engine cycle. Under operation, bottom zone brine temperature between 80°C and 100°C will be used to vaporize the Rankine engine working fluid while pond surface water ranging from 20°C to 30°C will be used to condense the vapors.

The component and system operating efficiencies are expected to be about 20% for the solar pond, 10% for the Rankine engine and generator and 2% overall. Although the conversion efficiencies may appear to be low, the ready availability, and low cost of the basic building materials (earth, water and salt) can make solar pond power systems cost competitive in certain locations.

Much of the development of solar pond power systems has been done by Ormat Turbines in Israel. The largest pond to date in Israel is a 6500 square meter pond at Ein Bokek on the Dead Sea. A 150 kWe generator unit that operates in a test mode as a peaking plant is connected to this pond. Another pond now under construction will be ¼ kilometer square and will supply the energy to a 5 MWe power plant. Testing is scheduled to begin in mid 1982. Installation of a 5 MWe plant at the Salton Sea will begin after the successful demonstration of the large system in Israel.

The Salton Sea is a terminal lake having a surface area of 360 square miles. Water flowing into the lake from agricultural drainage and natural runoff contains dissolved salts which are gradually increasing its salinity. Within a few years the salinity level will exceed 40,000 parts per million and aquatic life in the lake will be threatened. The Salton Sea Solar Pond Project is an outgrowth of a concept presented in the 1974 study, Salton Sea Project, by the U.S. Department of the Interior and the Resources Agency of California. This study recommended the control of the salinity in the Salton Sea in order to preserve the established ecosystem.

The Salton Sea Solar Pond concept is illustrated in the Figure 1. Water flowing into the lake contains salt at about 3000 ppm. Once dikes are constructed, water at an initial concentration of 40,000 ppm will flow from the lake into the solar and evaporation ponds. The net effect will be a transfer of salt from the Salton Sea to the ponds, and after 12 years of operation the salinity of the Salton Sea will be reduced to about 30,000 ppm. This application presents a unique opportunity for using solar energy to generate commercial electric power and simultaneously to provide an environmental benefit to the Salton Sea.

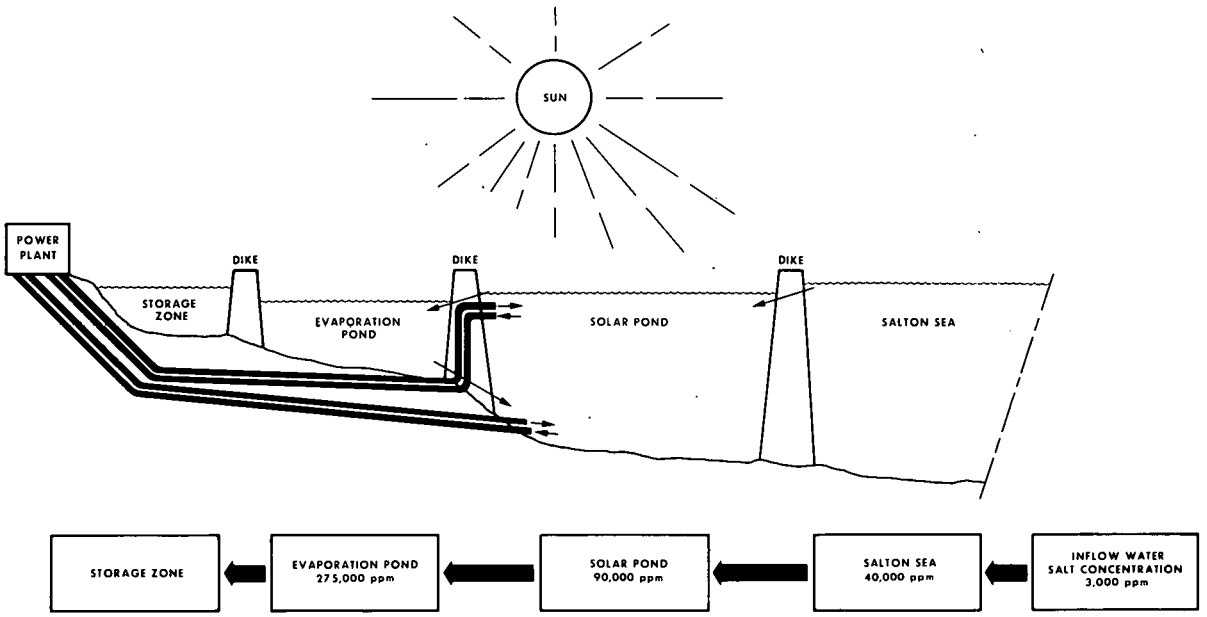


Fig. 1. Salton Sea Solar Pond Concept

SOLAR MATERIALS DEVELOPMENT

Barry L. Butler
Patrick J. Call
Patricia A. Roberts

Materials development supports the use of solar energy to provide a variety of energy products which include: fuels and chemicals; electric power; and heat for high and low temperature applications. Systems which concentrate, collect and transfer solar energy are used to generate these useful products. Within this framework, two materials categories can be defined: (1) optical materials subsystems which include reflectors, transmitters, and optical structures; and (2) thermal receiver and energy transport subsystems which consist of absorber materials, ceramics, metals and alloys, fluids and corrosion/compatibility. This paper summarizes the research methodologies and presents examples of specific research projects. The introduction of materials tailored for optical materials subsystems and receiver and energy transport subsystems are also highlighted.

For the conversion of solar energy into useful products, systems must be cost-effective and durable. The modification of existing materials and the development of a variety of new materials and materials combinations are in progress which will meet a wide variety of needs for solar applications. Before materials modifications and improvements can be accomplished, markets and solar energy conversion systems to meet these markets first must be identified and the system requirements determined. A range of energy needs as well as a variety of ways to supply those needs exists, and a large number of solutions to supplying energy from the sun is possible. A simple way to chart these possible solar solutions is given in Figure 1, which shows energy applications versus the concentrating power of a solar collecting device. The applications are ordered roughly according to the expected temperature necessary to satisfy the need.

Fuels and chemicals may provide very high energy per unit weight and volume, are transportable, may be easily converted to mechanical work, and can also be stored for long periods of time. Electricity is nearly as important as fuels and chemicals but serves different needs. Industrial process heat requires below 550°C to meet most processing needs. Space conditioning requires temperatures up to 100°C to provide comfort for building occupants.

The progression of solar energy concentration ratios in Figure 1 corresponds to the ability of a solar collector to deliver high temperature energy. The progression is from point-focusing systems (both parabolic dishes and heliostats), through line-focusing systems such as parabolic troughs, through flat plates, and finally to windows. In the point-focus and line-focus collectors, both reflecting and refracting optical systems are included.

Optical systems which consist of reflecting, transmitting, and structural materials are essential to the development of all solar energy collection systems. The relative importance of these materials is noted by the number of dots in each collector category in Figure 1. Materials research in these three areas can lead to very low initial cost solar collectors which meet the cost goals for delivered energy. Technology research and development plans which define specific needs for optical materials systems are included in Reference 1 and 2. Potential system benefit is the criterion for selecting materials research projects. The benefits to

life-cycle cost can come in one of three forms: lower cost, longer life, and improved performance. The development of optical materials systems is the highest priority because these contribute significant costs to any solar energy system. In Figure 1 the need for development of receiver and energy transport systems is biased toward the higher forms of versatile energy. Details of the work necessary in these areas are given in References 3, 4, 5, and 6. Materials requirements for systems are identified, and as R&D develops candidate solutions they are evaluated through field tests and finally in pilot demonstrations. The successful R&D products ultimately emerge in the commercial marketplace. Examples of current materials research projects in each state of this development are summarized in Figure 2. These have been developed by SERI and DOE.

An example of a current basic R&D project is the development of polymers which are UV stable for up to 10 years. Polymers have the potential to reduce the cost or prolong the life of a variety of solar energy systems. An R&D product in the feasibility stage is a platinum and aluminum oxide cermet. This material has demonstrated performance in the laboratory as a stable, high temperature selective absorber coating. Research in glass has resulted in the development of a low ferrous iron ion content glass which is thin, strong and has high transmittance. This glass has been pilot tested and is undergoing field evaluation by a variety of system fabricators. An example of a material which is ready for commercialization is a high temperature silicate-based paint which contains FeO_x, MnO_x, and CuO_x pigments. This paint is a non-selective absorber coating developed by Exxon Research and Engineering.

Materials development is being pursued to bring about a wider, more cost-effective utilization of solar energy. Through development of materials options for optical systems, energy receivers, and energy transport systems, materials impact the design of solar energy systems and provide the basis for less expensive, more reliable and improved performance conversion systems for solar energy utilization.

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TABLE I

STATUS OF CURRENT MATERIALS ACTIVITIES

I. RESEARCH AND DEVELOPMENT

	Project	Involvement*	Application
A.	Polyvinylidene Fluoride Polymers	I	Transmitting and Reflecting Films
B.	Polyacrylonitrile Polymers	I/U	Transmitting and Reflecting Films
C.	Black Cobalt	U/NL	Selective Absorbers to 400°C
D.	Cellular Glass	NL/I	Structures
E.	Platinum/Al_2O_3 Cermet	U/I	Selective Absorbers Above 400° C
F.	Improved Silver/Glass Mirror Protection	U/NL/I	Reflectors
G.	Corrosion Inhibition Research	U/NL/I	Fluid Energy Transfer Loops
H.	Metal/Fluid Compatibility	I/NL/U	Receivers
I.	Ceramic Fracture Toughness	NL/I/U	High Temperature Receivers
J.	Hollow Glass Spheres	NL/I	Solar Pond Covers
K.	Alternative Silver Metallization	I/NL	Reflectors

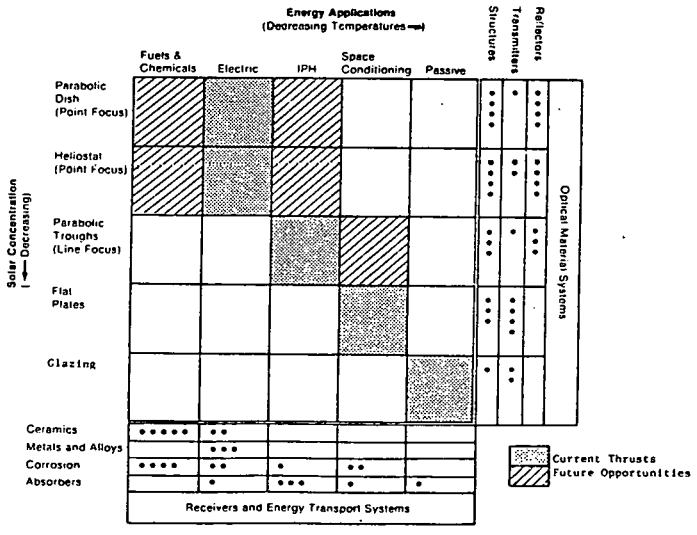
II. FIELD TESTING

	Project	Involvement	Application
A.	Thin Glass	NL/I	Flexible Mirrors
B.	Selective Paints	NL/I	Selective Absorbers Below 200° C
C.	Paper Optical Structures	NL/I	Single and Double Curved Reflectors
D.	Polymer/Composite Mirror Modules	NL/I	Lightweight Collectors

III. PILOT DEMONSTRATION

	Project	Involvement	Application
A.	Fusion Drawn Glass	I/NL	Glazings and Windows
B.	Black Chrome Coated Copper	I	Selective Absorbers
C.	Acrylic Reflector Film	I	Reflectors
D.	Silicone Impregnated Glass Cloth	I	Transmitting Material
E.	High Temperature Paints	I	Selective Absorber

*NL - National Laboratories
I - Industry
U - Universities



Materials Application to Solar Thermal Systems and Applications

COMPONENT RESEARCH AND TECHNOLOGY DEVELOPMENT

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Significant advances can be made in solar thermal technology by first identifying the technical and economic uncertainties in efficient collection, conversion, transport, storage and utiliziation of solar derived heat energy. These uncertainties can be removed by innovative design approaches and by development of new concepts. Since all components must serve a useful function when integrated into a solar system, the emphasis of the program is placed on those components expected to yield the highest benefit. At the Solar Energy Research Institute (SERI), in our role as the manager of this program element, several program opportunities have been identified and rank ordered based on the potential benefit to the overall solar thermal systems. These opportunity areas are discussed below with a focus on recent experiments conducted, or in planning stages, designed to demonstrate feasibility and to provide qualitative and quantitative evaluation of new concepts and components.

A technology requiring particular attention is the means by which solar energy can be more efficiently collected from the receiver aperture. Mechanisms capable of providing improvement in this respect are typically heat pipes, fluidized beds, small particle heat exchangers, entrained bed and packed bed heat exchangers. Two new devices have recently been tested at the Georgia Institute of Technology - Advanced Components Test Facility (GIT/ACTF). One involved a fluidized bed experiment utilizing a quartz tube containing various bed materials such as sand, copper shot, silicon carbide and alumina. The purpose of the experiment was to establish performance parameters for energy transfer with air as the working medium under solar operating conditions. Another GIT/ACTF experiment concerned obtaining performance data for a bank of sodium heat pipes. Distribution of radial and axial heat loads were determined and an evaluation of performance was made over the range of operating temperatures which the heat pipes will experience in a full scale receiver.

Another program opportunity exists by making available, for example, high temperature/high pressure steam for eventual high efficiency turbine use. An experiment was recently completed at GIT/ACTF in which a once-through steam receiver/boiler was operated producing superheated steam at 1500^{o}F and 1500 PSIA. During this test the critical dryout zone heat flux and the circumferential steam generator tube temperature variations were determined in order to understand potential thermal stress implications. In addition to the above, further work is required in improved receiver design in the areas of radiation trapping, flux containment (optical windows), and scaling potential from experimental devices to operational-sized hardware.

It is important to consider improved methods of transporting energy from the receiver to either point of use or storage while minimizing thermal losses and incurred costs. Thermal losses lead directly to increased system costs. The higher operating temperatures allow higher thermodynamic efficiencies and therefore yield substantial cost advantage. However, the increased temperatures also increase the

potential for higher losses both in transport and storage of thermal energy. The us of reversible chemical reactions to transport captured solar energy holds promise compared to conventional means because of its characteristic lower operating temperatures which are near ambient. Reversible chemical reactions, usually with the aid of catalysts, will absorb or release heat in the process. In solar applications, of the type envisioned, energy will be absorbed in the receiver using the endothermic reaction, transported to the point of use at low temperature and released using the exothermic reaction. Similar steps are used in the storage cycle application of this type of process. An experiment currently being conducted at the White Sands Solar Facility (WSSF) addresses the potential for this thermochemical process by carbon dioxide-methane reforming. Much of this effort is being used to define appropriate catalysts that will allow the required chemical reaction for extended duration while minimizing depletion. Critical in this regard is definition of a suitable CO_2-CH_4 operating ratio of mass flow rates. The series of experiments will address two critical questions with respect to technical feasibility and economic gain. There are presently other competing reactions being considered which accomplish similar end results. Analyses will be made to screen candidate reactions from the standpoint of addressing the two critical questions.

The captured energy can be used for a multitude of purposes. Many of these are currently being pursued at solar testing facilities. At GIT/ACTF and at SERI the feasibility of converting biomass to fuels using solar fluxes to promote flash pyrolysis has been investigated with considerable success. In addition, various water splitting cycles to produce hydrogen have been explored at WSSF and GIT/ACTF utilizing cadmium oxide decomposition and sulphuric acid vapor decomposition, respectively. Other potential uses of solar energy have been demonstrated at the Odeillo facility in France to produce calcium carbide (leading to acetylene production), at WSSF to process molybdenite ore displacing conventional fossil fuels and also at WSSF to gasify coal and oil shale. The energy can also be used to produce electricity and this potential is being explored by identifying candidate prime movers for further refinement and increased operational efficiency such as Stirling cycle heat engines. Critical component development is required in this area particularly in terms of linear alternator and regenerator design. Rankine cycle applications are also being investigated at GIT/ACTF in the Francia receiver and Brayton cycle development work is also being pursued. The Stirling cycle, however, holds much promise due to its high efficiency potential. Its characteristic smaller output limitation can be circumvented through ganging of engines.

Additional research is required to devise very low cost and durable concentrators. This activity is ongoing at the present time. Effort is also being devoted to developing hardware for more accurate one-axis and two-axis sun tracking to minimize energy losses due to collector misalignment. Needs exist for better field control/local control integration as well as economic improvements that minimize wiring lengths and reduce control installation costs. Furthermore, other non solar specific components that are now conventionally available seem to work poorly or fail sooner than predicted in the seemingly benign solar system environment. The cyclic nature of the solar operation imposes unique requirements on components such as pumps, sensors, probes, switches and the like. These components would ultimately require modification for solar specific use.

ADVANCED SYSTEMS DEVELOPMENT

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This paper summarizes the status of the Advanced Systems Development task managed by the Jet Propulsion Laboratory (JPL) for the U.S. Department of Energy. The Solar Energy Research Institute (SERI) has been selected by DOE to technically direct this effort and the NASA Lewis Research Center provides technical support for the power conversion subsystems.

Solar energy is the most powerful, inexhaustible resource available to man. Scientists and engineers at JPL, working with industrial contractors, are investigating low-cost methods of harnessing and converting the sun's radiation to electricity.

One of the most promising advanced systems reviewed during the past few years is the dish-Stirling system. In this design a very accurate, highly reflective parabolic dish tracks the sun and concentrates its rays on a high-temperature heat receiver coupled to a Stirling engine-alternator power conversion unit.

The goal of the advanced systems work is to deliver to the nation, by 1990, a system capable of generating electricity at a cost of 5 to 6¢ per kilowatt hour. The dish-Stirling system appears capable of meeting this goal at temperatures and operating conditions consistent with the state-of-the art in advanced technology.

The key element of this work is a dish-Stirling feasibility experiment scheduled for 1981. In this test program, the receiver and Stirling engine-alternator subsystem (shown in Figure 1), which was designed by the Fairchild Stratos Division of Fairchild Industries, Inc. and United Stirling of Sweden, will be mounted on JPL's 11-meter test-bed concentrator (shown in Figure 2) and subjected to a wide range of operating conditions. The test module will generate approximately 20 kilowatts of electricity. Testing of the power conversion unit

FIGURE 1 Stirling Receiver/Engine Alternator Subsystem

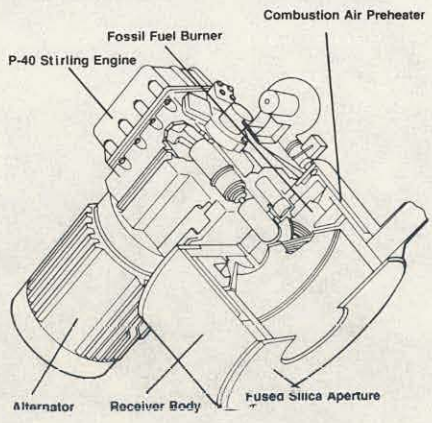
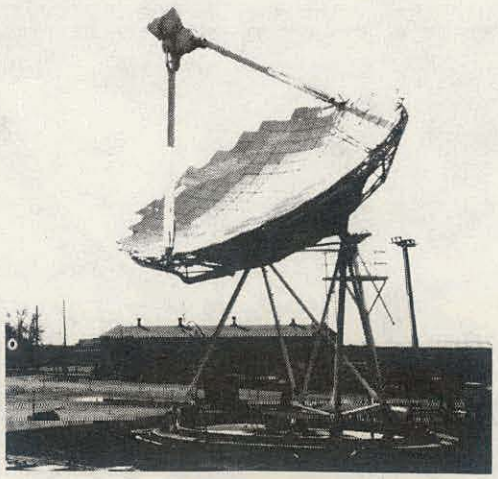


FIGURE 2 Test Bed Concentrator



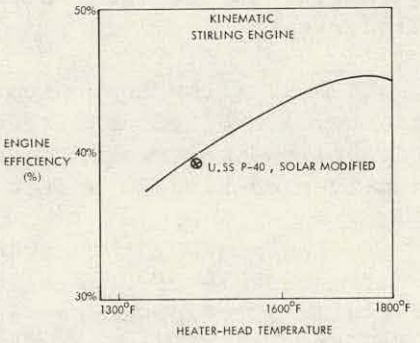
will begin at United Stirling's facility in Maalmo, Sweden in late 1981 and will culminate in a series of performance tests starting in June, 1981, at JPL's Parabolic Dish Test Site in the Mojave Desert at Edwards, California.

As may be seen in Figure 1, the module includes a combuster behind the solar energy receiver. Thus, the 20 kW_e can be delivered by fuel combustion, solar energy or a combination of the two. Future dish-Stirling solar-electric generating plants may be based on modules with collector diameters from 9 to 22 meters and corresponding power outputs of 15 to 100 kilowatts.

Smaller systems, even single modules, can be erected at remote sites to provide needed electricity for rural settlements, military installations, and developing countries.

A recent, in-depth, comparative study of solar-thermal systems performed by SERI shows that the most economically promising thermal-to-electric conversion technology for applications of 100 kilowatts to 10 megawatts is the parabolic dish with a Stirling engine. As shown in Figure 3, the Stirling engine's ability to operate at temperatures of 1500-1800°F enables it to achieve high conversion efficiency.

FIGURE 3 Heater-Head Temperature



This task also includes design and component evaluation of an advanced concentrator concept based on the use of cellular glass structural components. A concentrator designed by Acurex Corporation which can be mass-produced for less than $\$100/m^2$ is shown in Figure 4. Sample, full-scale gores will be tested during early 1981 to validate their structural and optical performance.

As an alternative to the Fairchild receiver, the General Electric Corporation is developing a low-cost heat pipe receiver with latent energy thermal storage as shown in Figure 5. In this design solar energy or thermal energy from an external combuster is delivered to latent energy storage cylinders. The thermal energy in turn, at an essentially constant temperature, is transferred to the Stirling engine heater head by means of a liquid sodium loop.

FIGURE 4 Acurex Concentrator Concept

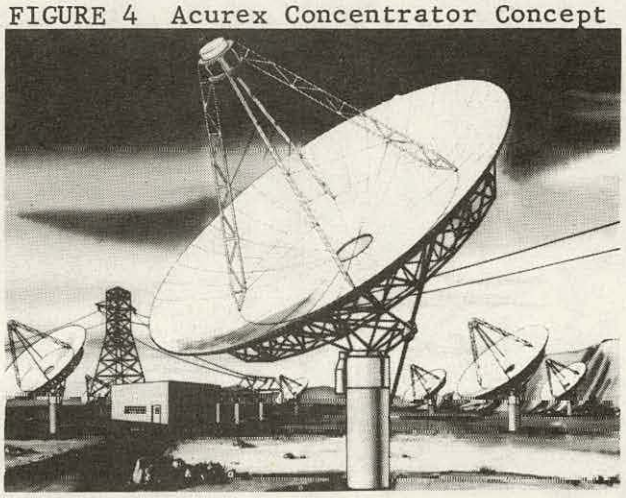
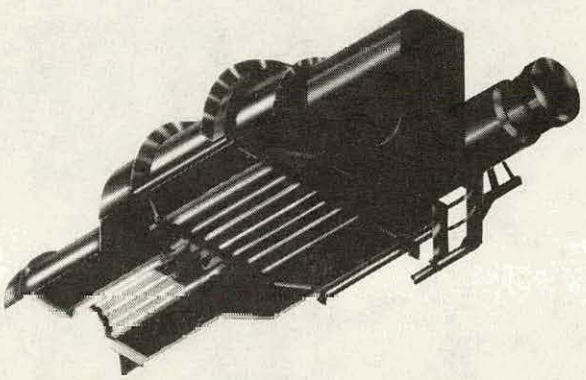


FIGURE 5 GE Solar Receiver



THERMOCHEMICAL ENERGY CONVERSION AND TRANSPORT-DEVELOPMENT OF CONCEPTS

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Thermochemical receiver systems provide a means of converting concentrated solar energy at high temperature into transportable chemical heat of reaction. Such systems are capable of delivering large quantities of heat at temperatures >500°C through process lines which operate at low temperature and low pressure. There are several gaseous chemical fluids which have been identified as promising candidates for use in thermochemical energy systems. Those solar furnace feedstocks whose conversion products are capable of delivering high temperature heat to storage include: $CO_2 + CH_4$, SO_3, NH_3, and $H_2O + CH_4$. It is the purpose of this paper to review the research presently being conducted at several universities in the United States to study the usefulness of these chemical agents in converting solar power to chemical heat of reaction and in transporting and delivering this energy to thermal storage.

At the New Mexico State University the $CO_2 + CH_4$ reforming-methanation chemical cycle and SO_3 dissociation are presently under experimental investigation with financial support from the Naval Research Laboratory, Solar Energy Research Institute, Solar Thermal Test Facility Users Association and Jet Propulsion Laboratory. A thermochemical test facility has been assembled in which $CO_2 + CH_4$ reforming reactors catalyzed by nickel or ruthenium are tested at temperatures up to 950°C with pre-mixed gaseous feedstock introduced at pressures up to four atmospheres and with mass flow rates of ½ to 3 gm/sec. The molar fractions of CO_2 and CH_4 in the reactor effluent are continuously monitored along with inlet and outlet gas temperatures and pressures, mass flow, and converter and heat exchanger temperatures. Electrical (resistive) heaters, simulating a focussed solar beam, deliver up to 6 kW of heat to an insulated cavity containing the reactor. The energy conversion rate and conversion efficiency are calculated directly from the experimental measurements. A separate laboratory facility is used at NMSU for testing SO_3 dissociation reactors. Gaseous feedstock is admitted to the system at pressures up to three atmospheres with mass flows of 1 to 5 gm/sec. By monitoring the SO_2 concentration in the effluent gas, the power converted by the reactor can be calculated. In December 1979 a prototype solar energy receiver utilizing a cavity converter and $CO_2 + CH_4$ chemistry was operated at the White Sands Solar Furnace. With 15 kW of solar power entering the receiver cavity, 5 kW of power was converted into chemical heat of reaction with the cavity operating at 900°C. It is anticipated that a second receiver will be tested at White Sands in January 1981. The conversion power level and the conversion efficiency are both expected to be appreciably higher in these forthcoming tests. Of equal importance to the project goals is the reconversion of the chemical energy to heat at high temperature in a remote energy storage facility. To meet this need, methanation catalysts and reactor configurations are being researched at NMSU. It is expected that a closed-loop, reforming-methanation energy delivery system will be operated in 1981 at the White Sands Solar Furnace.

At the Colorado State University the application of the reversible ammonia dissociation reaction to converting and transporting solar power is being studied experimentally by Drs. T.G. Lenz and J.H. Wright with funding from the Solar Energy Research Institute. The concept involves the introduction of liquid ammonia to a solar heated, high temperature reaction region where the feedstock is catalytically dissociated into nitrogen and hydrogen gases thereby absorbing a large fraction of the incident solar power. The solar receiver is comprised of catalyst-filled tubes forming the inner surface of the energy absorbing cavity. The cavity is surrounded by a countercurrent heat exchanger and thermal insulation. Of particular interest is the design and evaluation of fixed catalyst bed, cavity solar receiver elements. Single-tube catalyst packed tubular reactor-heat exchangers have been fabricated and tested in an effort to understand catalyst performance, the capabilities of materials and components at high temperatures and pressures, and the heat transfer and fluid transfer properties of different reactor configurations. In the CSU test facility liquid NH_3 is pumped through a stainless steel or Inconel countercurrent heat exchanger to a reaction region catalyzed by Ni, Pt, Fe, or Ru. The reactor operates at temperatures of 600 to 700°C, pressures of 100 to 300 atm, and mass flows of about 4 gm/min. 200 to 250 watts of thermal power is converted into chemical heat of reaction in a single tube reactor. The reactivity and power converted are calculated from the measured volume of gas evolved. In late 1980 or early 1981 a 43 tube solar receiver will be tested on the SERI Omnium G solar furnace. The cavity receiver will be configured in a cylindrical shape 1 foot in diameter by 1 foot in length with an 8 to 10 inch diameter aperature. The receiver is expected to convert 10 kW of solar power through the ammonia dissociation reaction.

At the University of Houston the feasibility of using the steam reforming-methanation chemical cycly in the conversion, transportation, and reconversion of solar power is being studied by Dr. J.T. Richardson. In the first phase of a project funded by the Solar Energy Research Institute an analytical study of several reformer reactor-receiver configurations has been completed. From this study it was concluded that the most promising system design would involve the use of packed bed tubular reactor surrounding a liquid-metal heat pipe which extends from one end of the reactor. This hot end of the heat pipe would be located in a concentrated solar flux. The heat pipe would thus collect and transfer concentrated, high temperature solar power to the steam-reformer reactor. The reformer effluent (an energy rich mixture of CO and H_2) could then be piped to a methanating reactor where a fraction of the converted solar power could be recovered. The experimental phase of this project, now underway, involves the construction and operation of a steam-reforming reactor test facility. A pre-heated mixture of a few hundred standard cubic feet per hour of methane and steam is piped to the reactor test stand. A typical reactor will be comprised of a 2 inch diameter by 7 foot long heat pipe surrounded by a 6 inch diameter by 5½ foot long reactor pipe which contains the packed catalyst bed. The 1½ foot open end of the heat pipe is exposed to a 30 kW infrared heater which simulates a focussed solar beam and provides the heat of reaction. Reactor effluent is sampled and its composition is monitored by two gas chromatographs. From these data the power converted and the conversion efficiency are calculated. The exit gas is vented to the atmosphere in a 40 foot flare. A steam ejector is used to dilute and boost the gas to higher altitude. The system is controlled by an on-line, real-time computer.

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FUELS AND CHEMICALS RESEARCH AND EXPERIMENTS

Charles B. Benham
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As the technology for solar thermal energy matures through development of and application to electrical power systems in the utility market sector, additional markets using this technology are being identified. This presentation describes DOE sponsored research on the use of solar thermal energy in chemical processes for producing fuels and chemicals. Table 1 lists the projects described in this report.

TABLE I - Fuels and Chemicals Projects

TOPIC	AGENCY	PRINCIPAL INVESTIGATOR
Thermochemical Hydrogen	Institute of Gas Technology	Ron Cary
Thermochemical Hydrogen	General Atomic Co.	Gottfried Besenbruch
Calcium Carbide	Institute of Gas Technology	Dennis Duncan
Coal Gasification	Lawrence Livermore Laboratory	David Gregg
Biomass Pyrolysis	Princeton University	Michael Antal, Jr.
Biomass Pyrolysis	Solar Energy Research Institute	Charles Benham

The Institute of Gas Technology has been involved in thermochemical water splitting research since 1972. One of the current research projects involves a three-step hybrid cycle:

$Cd\ (s) + 2H_2O\ (l) \rightarrow Cd(OH)_2\ (s) + H_2\ (g)$ electrochemistry

$Cd(OH)_2\ (s) \rightarrow CdO\ (s) + H_2O\ (g)$ thermochemistry, 350 to 400°C

$CdO\ (s) \rightarrow Cd\ (g) + 1/2\ O_2\ (g)$ thermochemistry, 1200 to 1500°C

This hybrid cycle has an extremely attractive maximum attainable efficiency (about 80%), and a high flowsheet (conceptual solar process) efficiency of 50 to 55%. All steps of the cycle have been demonstrated with recycled materials. The cadmium oxide decomposition step was tested using solar energy at the U.S. Army solar test facility in White Sands, New Mexico.

General Atomic has developed a pure thermochemical water-splitting cycle based on a main reaction involving H_2O, I_2, and SO_2:

$2H_2O + SO_2 + I_2 \rightarrow 2HI + H_2SO_4$

$2HI \rightarrow H_2 + I_2$

$H_2SO_4 \rightarrow H_2O + SO_2 + 1/2\ O_2$

The last step, decompostion of sulfuric acid, was carried out in a solar heat exchanger at the Georgia Institute of Technology Advanced Component Test Facility. The tests were conducted at operating temperatures of 750 to 900° with an H_2SO_4 feed rate of approximately 1 mol/min. The solar heat exchanger consisted of 28 parallel tubes, each 92 cm long by 2.5 cm outside diameter, welded to inlet and outlet leaders. Total dimensions were approximately 92 by 92 cm aspect area. Decomposition products were measured at several temperatures.

The Institute of Gas Technology demonstrated the technical feasibility of making calcium carbide from lime and coke using solar heat in a series of experimental runs conducted at the Odeillo (France) laboratory of the Centre National de la Recherche Scientifique (CNRS). Calcined lime reacts with coke or charcoal to produce calcium carbide, as follows:

$$CaO + 3C \rightarrow CaC_2 + CO$$

Calcium carbide reacts with water to produce acetylene:

$$CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2$$

The carbon monoxide produced at the same time as the carbide, and the acetylene released from the carbide, are important building blocks for fuels and petrochemicals. The tests at Odeillo were conducted using a 2-kw solar furnace having a focus whose cross-sectional shape is roughly an ellipse which provided temperatues of about 2000°C needed for the reaction between lime and coke.

A coal gasification experiment using solar energy was conducted at the White Sands Solar Facility by researchers from the Lawrence Livermore National Laboratory. A gravity-feed gasification reactor was used in the experiment. Focussed solar radiation entered the reactor through a quartz window which was kept free of deposits by steam flowing across the window.

Researchers from Princeton University tested a quartz reactor for pyrolyzing biomass materials. The tests were conducted at the Georgia Institute of Technology Advanced Component Test Facility using cellulose, hardwood sawdust, ground corncobs and Kraft lignior as feedstocks.

A bench-scale entrained-flow stainless steel reactor was used by researchers at the Solar Energy Research Institute to pyrolyze wheat straw and other agricultural feedstocks. The laboratory tests used controlled electric heaters to simulate the solar heat source. Projections were made on the amount of diesel fuel which could be produced from the pyrolysis gases in a Fischer-Tropsch conversion process. An entrained-flow pyrolysis reactor-receiver was designed and fabricated for testing on a 6-m diameter paraboloidal solar concentrator at the SERI test facility.

THE ROLE OF QUALITY ASSURANCE AND STANDARDS IN DEVELOPING SOLAR THERMAL COMMERCIALIZATION TECHNOLOGY

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In the process of developing a Standards Development Plan for solar thermal technology, widely divergent view within the technology were expressed on the role of standards in meeting the legislative directives to develop a sound commercial solar thermal industry. It is suggested that Quality Assurance and Standards Development which encompasses Performance and Reliability requirements has, or can play, a larger role in developing commercialization of the new industry beyond that which would be expected in an established industry. A large percentage of codes applicable to the technology presently exist in some modifiable forms, and it is only necessary to incorporate in the body of these documents requirements to permit jurisdictional coverage and acceptance to their use. Those codes and standards unique to the solar thermal technology need to be identified promptly and development begun by the industry for subsequent submission to the consensus process through ANSI. There are long lead times involved in producing a working standard or code and to effect modifications to existing codes. It is essential for the development of commercially successful solar technologies by the end of the decade to have available over the next five years data on the effects and needs of codes, standards, certification procedures, etc. Since the normal market place forces do not presently exist to promote the development of codes and standards this role can best be achieved by agency sponsorship.

One of the lessons learned from related solar technologies is the need to work with and develop implementation procedures for codes and standards at the local level. Performance and Reliability Analysis is considered to be one of the essential functions of a Quality Assurance program and an early aim of the program should be to establish an overall data gathering system. This system will permit the local researcher to conduct and report his own qualitative evaluations but also will require he submit statistical operating and performance data to a unified data gathering system for analysis.

Management projections, performance data gathering systems and standards development and implementation procedures to meet the aims expressed above are presented as a series of line function diagrams.

INNOVATIVE FINANCING FOR INDUSTRIAL APPLICATIONS OF SOLAR TECHNOLOGY*

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The capital intensive nature of large area, solar industrial process heat systems presents a major deterrent to their mass produced commercialization and acceptance by industry. For example, present quoted installed costs of large area ($\geq$ 100,000 ft^2), parabolic trough systems, taken together with presently available investment tax credits and accelerated depreciation schedules, indicate that on a life-cycle cost basis, allowing a 15% after-tax, market rate of return on solar investment, these systems are very near to being competitive with the cost of distillate oil. However no private enterprise, non-federally subsidized, market appears to be developing for these solar systems, even though many industries in every region of the country use large quantities of 350°F to 500°F process steam which parabolic troughs are able to provide at reasonable efficiency.

The primary reason for this lack of early market penetration is the high initial capital investment required from the industrial user. A 100,000 ft^2 (aperture area) parabolic trough system can be installed today for approximately $3,000,000. In southwestern locations this system should provide about 25,000 MBtu of process heat annually, replacing about 5000 barrels of oil. However the cost of investment capital is high and its availability is limited. Most companies have higher priorities for investment opportunities than provided by a relatively untried and high-risk solar technology.

This paper will describe work underway at the Lawrence Livermore National Laboratory, in conjunction with members of the Winthrop Financial Co., Inc. and other consultants from the financial and tax law community, to determine methods of financing large area solar process heat installations which, with proper incentives, would be attractive to potential industrial end-users.

Two approaches will be briefly described below.

The Solar Management Company (SMC)

This approach utilizes a limited partnership structure in which the SMC would serve as the general partner in forming a partnership to construct, operate, manage and own a solar installation at an industrial site. The SMC would form a separate partnership to own each solar installation.

The limited partners in each partnership provide the necessary equity capital and participate in all income and losses. Debt financing is provided by conventional lending sources (e.g., banks, insurance companies, pension funds). The ratio of debt to equity capital for a particular partnership would be between

*This work is supported by the Office of Solar Applications to Industry, Department of Energy.

(3-1/2 to 1) and (4 to 1). The partnership would own the equipment and sell energy to the end-user on a "take-or-pay basis". [End-user agrees to take and pay for all energy produced by the solar system over the length of the contract.] The "take-or-pay" contract would call for price escalations in solar generated steam delivered from year to year, but at a discount to generally escalating fossil energy costs.

The tax incentives (investment tax credits, depreciation and interest deductability), expenses and cash flow would pass through to the individual limited partners. Individuals in the highest tax brackets will be able to best utilize these tax incentives and therefore find a high risk investment of this nature most attractive.

The partnership would be responsible for operating and maintaining the solar installation, taking all responsibility off the end-user. The solar management company would either form an equipment management company for this purpose or possibly contract for the services of an independent company. The equipment management company would most likely operate and maintain a number of solar installations, some or all under the management of one solar management company as the general partner representative of the individual partnerships.

This management structure, consisting of a general partner and a number of limited partners contributing equity capital, together with heavy loan leveraging, is well known in the real estate, oil and gas, and equipment financing industries. Many commercial buildings, shopping centers, and other multi-million dollar construction projects are financed in this way. Over one billion dollars per year is raised to fund oil and gas exploration and development programs.

There are two key considerations that must be changed through legislation for this method of financing to be viable for large area industrial solar systems:

a) The "at risk" provision enacted by Congress in the 1976 Tax Reform Act would have to be waived as it presently would pertain to solar collecting equipment (currently only real estate investments are exempted from this provision).
b) Some existing or new governmental agency must be empowered to make government guarantees available to the debt since it is unlikely that conventional lending sources would consider a "take or pay" contract as iron-clad security to a long term lending commitment.

Conventional Lease Financing

At the presently prevailing installed costs of large area industrial solar systems this form of financing is not yet attractive, either to a leasing company (lessor) or to a potential end user (lessee). However if the use of the solar management company technique were to be successful in substantially increasing the production level of the solar collector manufacturers, they should be able to justify substantial capital investment leading to mass production capability of parabolic troughs (and other collector types as they reach the commercialization stage). In this way system costs should come down substantially, perhaps to the level of \$20 per ft^2. Were this to happen, solar provided heat would become competitive with oil and gas, at first in the sunbelt regions. The lease financing approach would then become an attractive and simple way to finance these systems, removing the burden of large capital investment from the end-user and placing it with the leasing company.

INDUSTRIAL PROCESS HEAT CASE STUDIES: POTENTIAL FOR SOLAR THERMAL APPLICATIONS

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The industrial sector presently uses over-one third of U.S. energy supplies, and is therefore a crucial element in any strategy aimed at reducing U.S. dependence on imported fuels. In considering the use of solar thermal technologies to provide industrial process heat (IPH), the temperature dependent nature of the efficiency and the cost of solar systems must be recognized. A technique of "end-use matching" seeks to minimize the delivered cost of solar energy by matching the operating temperature of solar collectors as closely as possible to the temperature required by the industrial process. A value is placed upon the "quality" of energy. The approach is equivalent to an attempt to maximize the Second Law (of Thermodynamics) efficiency of the process.

The industrial case studies program at the Solar Energy Research Institute was initiated to test the validity of this theoretical concept. The goals of the program can be summarized as follows:

- o to determine the near-term feasibility of solar IPH technology;
- o to identify energy conservation measures, particularly as they would impact solar installations;
- o to identify characteristics of IPH systems that effect the potential use of solar energy;
- o to test SERI's IPH analysis software;
- o to disseminate information to the industrial community; and
- o to provide inputs and guidance to the national solar research and development program.

Research at SERI has determined that the most immediate market for solar thermal technologies is to provide heat to those industrial processes operating at temperatures less than 288°C (550°F). Users of IPH in this temperature range are extremely diverse, geographically dispersed, tend to burn premium fuels, and thus may present a combination of circumstances favorable to near-term solar applications using currently-available equipment.

Industry consumes energy to fuel only a limited number of unit operations. These operations have been ranked according to suitability for solar applications. By applying the end-use matching concept, it has been found that low-temperature liquid heating for applications such as cleaning, pasteurization, dissolving and distillation are most favored. The production of hot air for baking and curing operations appears least suitable. However, since the drying process is possible at almost any temperature, it presents a unique opportunity to use direct solar radiation to economically dry materials such as coal, animal feed and biomass prior to combustion.

The impact of energy conservation measures on industrial practices has to be anticipated in planning any solar installation. Some conservation measures could supplant or degrade the performance of an ill-planned solar system. However, trends in energy conservation technology and the economic circumstances favoring their use should also assist solar applications. For instance, a shift from the conventional steam boiler to high temperature water (HTW) generators, as a means of saving energy, would allow the introduction of more economical solar systems.

A list of environmental, process, economic and company-related factors which directly influence the economic potential of solar industrial applications has been identified. Such factors include: areas of high insolation in a nonfreezing climate; low temperature, continuous, liquid-heating processes; high conventional fuel costs; and a management and work force capable of maintaining a solar system and willing to take some of the risks associated with an emerging technology. The availability of vacant land is a major constraint to the widespread industrial use of solar energy. Many low-temperature users of IPH are located in urban or suburban environments. In general, the use of roof space does not appear to be economically practical due to the high degree of reinforcement often required. Also, low-temperature users tend not to operate on weekends and thus heat storage becomes an essential feature of a solar design.

Experience gained from the case study program together with information obtained from the IPH field test projects has been valuable in updating the computer software used to analyze possible solar applications. Though each application requires individual analysis, certain conceptual configurations arise much more frequently than others. For instance: storage seems a necessary feature of most plants; indirect systems whereby a heat transfer fluid (including water) is circulated through a closed collector loop seem preferred; and parasitic electrical power consumption and the problem of piping large ducts into an existing plant often tend to preclude direct air-heating systems. Findings such as these provide valuable imputs to solar research and development programs.

Contact with industry has provided for a valuable exchange of information. The case study work has been widely circulated in reports, presentations to conferences, journal articles (1, 2, 3, 4, 5) and has been favorably received. Additionally, the computer software, when completed, will be available to industry to assist in their decision-making process.

Predictably, case study analyses have shown solar thermal technology to be uneconomic in the near-term, except in rare instances. However, the experiences gained suggest a change in the method of selecting industries for future field test experiments and market demonstration tests. More favorable applications could be determined by making contact with interested parties in industry and using the case study methodology to screen candidates. Bids could then be solicited for each of several favorable plants and evaluated for construction on a basis consistent with other capital projects. The demonstration of reliable solar technologies producing energy at costs shown to be competitive with traditional fuels will significantly speed the widespread commercialization of solar technologies. Even if the area of applicability is geographically limited at first, satisfying a localized market would provide a considerable boost to the solar industry.

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AGRICULTURAL SOLAR RESEARCH PROGRAMS - AN OVERVIEW AND HIGHLIGHTS[1]

Landy B. Altman,[2] Paul R. Barnes,[3] James L. Butler,[4]
Conrad V. Chester,[3] and James M. Schreyer[3]

The development of the U.S. agricultural system was based on abundant supplies of low-cost energy which accounted for only a small fraction of the cost of production. The cost of energy, however, has significantly increased during the last few years and we can expect energy cost and availability to be important factors in agricultural production in the future.

The Department of Energy (DOE), formerly the Energy Research and Development Administration (ERDA), in conjunction with the Department of Agricultural (USDA), has supported an agricultural solar research program since 1975. The major goals of the program were: (1) to develop techniques and equipment for applying solar energy to agriculture as an alternative to the use of fossil fuels and (2) to reduce the dependence of agriculture on depletable fuels.

This research program has been a cooperative effort among USDA, DOE, universities, industry, and the Oak Ridge National Laboratory (ORNL). DOE research funds were passed through to the Science and Education Administration (SEA) of the USDA, which administered most of the research. The research programs developed into six categories; five of these were managed by USDA (SEA), and the sixth which involved commercial greenhouses was funded directly by DOE. The five USDA-administered categories have been: (1) grain drying, (2) food processing, (3) drying crops other than grain, (4) animal shelters, and (5) greenhouses associated with rural residences.

Each of the five research areas was assigned a principal investigator associated with SEA and a co-principal investigator representing state agricultural experiment stations to oversee the projects. Proposals were solicited each year for each area of research, and peer panels selected the best proposals for funding. The number of projects in each category ranged from 8 to about 14, and each project had a project manager to oversee and manage the research activities. A large portion of the research was conducted at universities and SEA-AR research stations.

Technical management assistance to DOE was provided by the Oak Ridge National Laboratory. This assistance included: (1) review of the approach, progress, and results of research activities; (2) serving on peer review panels;

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[1]Research sponsored by the U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

[2]USDA-SEA, Beltsville Agricultural Research Center, Beltsville, MD 20705.

[3]Energy Division, Oak Ridge National Laboratory, Oak Ridge, TN 37830.

[4]USDA-SEA, Southern Agricultural Energy Center, Tifton, GA 31973.

(3) visits to the solar energy research facilities and providing technical assistance to the researchers, when appropriate; and (4) participation at technical workshops and meetings involving direct or related research activities associated with the agricultural program.

For the past five years, much of the research has concentrated on the approach and design details of solar systems for specific agricultural applications, such as grain drying. The use of solar systems for multiple applications, such as grain drying and heating animal shelters, has also been investigated as a means to achieve better utilization and economic feasibility.

Recently, the use of crop residues as a source of on-the-farm fuel has been encouraged. DOE has emphasized, in recent years, studies of combining various energy sources into an energy unit. Biomass such as crop residues can be combined with solar systems to solve special problems such as drying grain in hot, humid regions. Crop residues can also provide the primary source of energy for many agricultural applications. Studies are continuing to determine the best means of collecting, handling, storing, and utilizing crop residues.

During the past five years many practical solar systems have been designed and developed for agricultural applications. Collectors have been built into farm buildings using the building components to collect solar energy. Roof, sidewall, and attic collectors have been built and demonstrated. "Collectorless" solar grain drying, using ambient air and careful fan scheduling, has been developed at Nebraska State University for the North Central region. A solar collector/storage wall has been developed for swine shelters. Nighttime insulation and soil heating have been studied for greenhouses. Both peanuts and corn have been dried by solar energy collected the previous winter by a desiccant drying system, and fish, vegetables, and fruit have been dried in simple, solar-concentrating units.

The overall program has been very successful as demonstrated by the many achievements in utilizing solar energy for agricultural applications. The research has been documented in technical publications and journals as well as DOE reports. The solar system designs developed under this program are now being applied in demonstration projects administered by USDA-Extension. Many of these solar systems are now economically competitive with fuel oil or electricity as sources of heat and are being installed on many farms. In Illinois, for example, hundreds of new farm buildings with integral roof and wall collectors have been built. Scores of livestock shelters have been equipped with the integral storage-wall collector developed at Kansas State University. The plans for these and other collectors are available through the Agricultural Extension Service.

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SOLAR ENHANCED OIL RECOVERY, A POTENTIAL EARLY MARKET FOR INDUSTRIAL SOLAR ENERGY

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One way that solar energy differs markedly from fossil energy for most industrial applications is that the energy cost is strongly affected by the "solar suitability" of the application. For this reason, we can expect the early years of solar market penetration to be characterized by economic conditions which are simultaneously very favorable for some loads and very unfavorable for others. For many reasons, steam enhanced oil recovery appears to have a relatively high solar suitability, and as a result, it may play an important role in the emergence of solar energy as a viable alternative energy source for industry.

Some of the reasons for this high suitability are intrinsic to the application. They have to do with the temperature requirements, the need for storage, the land availability, and so on. These are discussed in some detail in Reference 1, where they provide a qualitative understanding of the relatively favorable results of an economic analysis of Solar Enhanced Oil Recovery (SEOR).

In addition to these intrinsic features, however, there are a number of extrinsic reasons favoring the early development of SEOR which pertain to the specific institutional and economic situation of the present and near future. For example:

- o It is not unusual in the oil industry to make large investments in projects which have relatively high risks, and which may take many years to break even. This characteristic is not unique to the oil industry, but, compared to an industry which is more averse to taking risks, there may be less resistance to SEOR because of the fact that large-scale, high temperature solar energy systems have not yet been widely utilized.

- o Tertiary oil recovery is a growth industry in the U.S.; hence, costly retrofit situations can be avoided.

- o Large amounts of capital are presently available (though, admittedly, there are numerous other ways the oil companies can invest it for oil exploration and production).

- o For the very near future, there is a favorable combination of federal incentives which can be applied towards SEOR. The combined effect of the investment tax credit, depreciation deductions, and Tertiary Incentive Revenues (TIR) can result in government subsidization of more than 80% of the initial system cost.

As a consequence of these favorable conditions, both intrinsic and extrinsic, it is reasonable to expect SEOR to develop earlier and more rapidly than most other industrial solar applications. To some extent, it may be possible, therefore, to consider SEOR as a "prototype" market for solar IPH, in the sense that several trends and issues which can be anticipated for the larger industrial market may be visible much earlier in SEOR. For example, there is the issue of adaptation of the energy load to the energy source. It is generally accepted that for feasibility studies and preliminary economic analyses, one should not assume that any changes are required in the industrial process as a result of the introduction of solar energy, i.e., the solar system output should mimic a conventional system. This policy avoids the fallacy of externalizing the solar energy costs (e.g. by reducing productivity or efficiency of the process considered as a whole). In fact, however, it will often occur that process modifications which are truly cost-effective are possible. For SEOR these may include:

(1) the possibility of generating steam at lower pressures than is common with off-the-shelf fossil-fired boilers;
(2) injecting steam at a lower average rate than conventional practices, in order to match the project lifetime to the solar equipment lifetime;
(3) injecting steam intermittently, or at a non-uniform rate, in order to reduce storage requirements and minimize fuel use.

Another important aspect of SEOR as an early solar IPH market is the role it could play in commercializing solar collectors, i.e., stimulating price reductions as a result of increased production. Current levels of concentrating collector production are so low that significant economies of scale have not been realized. Some progress has been seen in this regard, at least for trough collectors, but it is widely believed that this price reduction trend will continue, and that true economies of production scale would be seen at levels of millions of square feet per year. Once cost reductions have been achieved, one can expect solar economics for other applications as well to become more favorable. Thus, SEOR could play a critical role as a "seed crystal" in the commercialization process, and the timetable for solar market penetration as a whole could be very sensitive to progress in this area.

[1]K. D. Bergeron, "Solar Enhanced Oil Recovery, An Assessment of Economic Feasibility," Energy, 4, 1127 (1979).

SECTION 7

OCEAN SYSTEMS

OCEAN SYSTEMS

Program Chairman: *Richard A. Woldin,* Lockheed Missiles & Space Company
DOE Advisor: *Robert Cohen*
Overview Presentation: Tuesday, December 9, 8:30 A.M.

"Ocean Thermal Energy Conversion" 2-1
John R. Justus, Congressional Research Service

SESSION I: Tuesday A.M.
Technology Review

"Overview of the 7th Ocean Energy Conference" 7-1
Robert Cohen, DOE, and *Robert Scott,* Gibbs & Cox, Inc.
"Department of Energy, Ocean Systems Program Summary" ..... *
William Richards, DOE
"OTEC 40 MW Baseline Design" 7-3
J. Paul Walsh, VSE Corporation

SESSION II: Tuesday P.M.
Regional Markets and Applications

"OTEC Island Markets" 7-5
John P. Craven, University of Hawaii at Manoa
"U.S. Mainland OTEC Markets" ..... *
Byron Washom, Advanco Corporation
"The Development of Ocean Energy in the Third World" 7-7
Frederick E. Nàef, Lockheed Missiles & Space Company, Inc.
"OTEC Baseload Power Cost Assessments" 7-9
James W. H. Denton and Robert H. Douglass, TRW DSSG
"OTEC Ammonia Production" ..... *
J. P. Schiller, SOLARAMCO

SESSION III: Wednesday A.M.
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OVERVIEW OF THE 7th OCEAN ENERGY CONFERENCE

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Robert Scott, Program Manager,
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1. Introduction

The 7th Ocean Energy Conference was held in Washington, D. C. between June 2 and 5, 1980. The Conference was sponsored by the Division of Ocean Energy, U. S. Department of Energy and organized by Gibbs & Cox, Inc. The Conference was attended by 564 people, including 61 representatives of the press, and included 80 technical papers and exhibits by 20 organizations.

2. Principal Speakers

The Conference included addresses by key DOE and political figures with interests in ocean energy development, as summarized below in the order of presentation.

Congressman Baltasar Corrada, Resident Commissioner of Puerto Rico, was the Keynote Speaker. He noted Puerto Rico's nearly total dependence on imported oil for energy. Puerto Rico's strong support of OTEC and the availability of excellent sites for OTEC demonstration were highlighted.

Governor George Ariyoshi of Hawaii addressed the Plenary Luncheon, emphasized Hawaii's commitment to OTEC and their interest in the pilot plant program. He noted the ability of islands to contribute to the entire nation's energy needs by supporting energy-intensive industries, and the use of OTEC-produced hydrogen and ammonia for fuel.

Rep. Don Fuqua of Florida, sponsor of H.R. 5796, addressed the Banquet. He noted the urgent need for a federal commitment to early commercialization and incentives to promote industry participation. The use of OTEC to produce ammonia for fuel cells and for offshore mining were cited as long-term goals.

3. International Overview

Four representatives of the international ocean energy community addressed the Plenary Session. Mr. Bengt Lachmann of EUROCEAN, a consortium of European industrial firms, noted that they are considering OTEC in combination with desalination and agriculture, particularly for developing countries.

Clive Grove-Palmer, of the Energy Technology Support Unit (United Kingdom) summarized wave energy programs in Norway, France and the U.K., which are in the early development phase. One to 2 MW pilot projects are envisioned in the next 10 years.

Phillippe Marchand of CNEXO, the French equivalent of NOAA, indicated that the French program is directed primarily toward OTEC and includes feasibility studies of small (1-15 MW) plants for tropical locations such as Tahiti, component testing and a Pilot Plant for the mid-1980's.

Dr. Hiroshi Kamogawa of Toshiba Corporation indicated that the Japanese government has authorized a 1 MW OTEC plant, to be operational in 1984. A 1 KW OTEC experiment was recently deployed at sea. Japan's KAIMEI wave power platform is operating in the Sea of Japan producing 800 KW.

4. Working Group Reports

Five workshops were held during the Conference, to highlight key issues appropriate to the development of the pilot plant and commercialization of ocean energy. Key conclusions and recommendations are summarized below.

Ocean Engineering - In all areas except the power riser cable, the technology exists today for design of a 40 MW pilot plant. The pilot plant is essential to demonstrate economic operations, and as a vehicle to extrapolate technology to commercial sizes. Other recommendations are as follows:

1. Proceed with required testing and development for the power riser cable as soon as possible. This work is critical to OTEC pilot plant development.
2. Examine other OTEC options such as bottom sitting towers and land-based plants.
3. Construction facilities do not exist in the U.S. for large concrete platforms.
4. Evolutionary development of CWP's from 30 to 60 to 100 ft. diam. is recommended.

Power Systems/Biofouling/Corrosion Control - This working group concluded that the design and development of the pilot plant must receive top priority. Specific conclusions and recommendations include:

1. Power system and heat exchanger technology exist for the pilot plant, but evolution of economies and commercialization require long term testing.
2. Shore based facilities, e.g., Seacoast Test Facility are recommended for testing.
3. Further developments are required for more cost-effective reliable heat exchangers, as well as total power generating systems, probably involving shore-based testing.
4. The open cycle should be pursued as a long-term economic approach to OTEC, but should not dilute the effort to build a pilot plant.

Alternate Ocean Energy Systems - The principal conclusion of this Working Group was that funding for non-OTEC alternatives (waves, currents, salinity gradients) has been inadequate, and that funds for alternate systems should be specifically dedicated so that they cannot be redirected to other programs. It was also recommended that program plans be established in each alternate technology area, defining specific goals and priorities. Valid resource identification is a major need.

Industrial Development - The Industry Development Working Group concluded that considerable progress has been made in the area of industry development. Specific recommendations included the following:

1. Undertake pre-solicitation releases of procurement documents in order to receive comments and ideas from potential bidders.
2. Study small plants suitable for developing nations and islands (less than 10 MW).
3. Study the Energy Island concept, including logistics, trade, and dispersal.
4. Undertake international cooperative agreements on major demonstration projects.
5. Require that the pilot plant be designed to be economically self-sufficient.
6. Undertake a parallel, concurrent, multiple demonstration plant program.
7. Require bidders on the pilot plant to describe their commercial strategy.

Environmental/Resources/Siting - The principal conclusion of this Working Group was that the pilot plant must comply with the National Environmental Policy Act of 1969 and that compliance activities should begin early. Specific areas of concern include:

1. Withdrawl of ocean waters from the surface and at 1000 meters, causing entrainment.
2. Discharge of waters near the thermocline causing redistribution of properties.
3. Biocide release for biofouling control.
4. Working fluid release from spills or leaks, and effects on resident organisms.
5. Power cycle erosion/corrosion from seawater passage.

5. Future Conferences

It is currently planned to hold the 8th Ocean Energy Conference in the Washington, D.C. area in early June, 1981, organized by the Marine Technology Society. The Conference will highlight OTEC-1 accomplishments, pilot plant design concepts and the latest legislative initiatives and prospects.

OTEC 40 MW BASELINE DESIGNS

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During the course of the OTEC development, two conceptual designs of complete OTEC systems have been produced. They both are on floating platforms. One has the shape of a spar; the other is barged-shaped. There are two versions of the barge-shaped system -- one is moored and sends the power it generates ashore over a cable; the other grazes seeking the warmest surface water and produces a product (such as ammonia) which is sent ashore by ship. Design and development of the subsystems -- cold water pipe, heat exchangers, riser cable, platform, etc. -- using both anaytical and experimental techniques has been going on for several years and is continuing. The baseline design process takes these subsystems and integrates them into a working OTEC system. This paper describes these integrated 40-MW "baseline" designs.

Design Requirements The requirements that these baseline designs must meet were established by the Department of Energy and some of them are as follows:

- o Produce an average, yearly, net power of 40 MW at the onshore busbar.
- o Have a 30-year useful life.
- o Survive the 100-year storm with and without the cold water pipe attached to platform.
- o Construction in U.S. facilities.

Baseline Designs Two very different platform types were chosen for the baseline designs, the spar and the barge. The principal advantage of the spar shape is that its response to large waves is the least of any floating platform. The advantage of the barge shape is that similar barges have been built. The spar pilot plant baseline design is shown in Figure 1.

Spar Pilot Plant

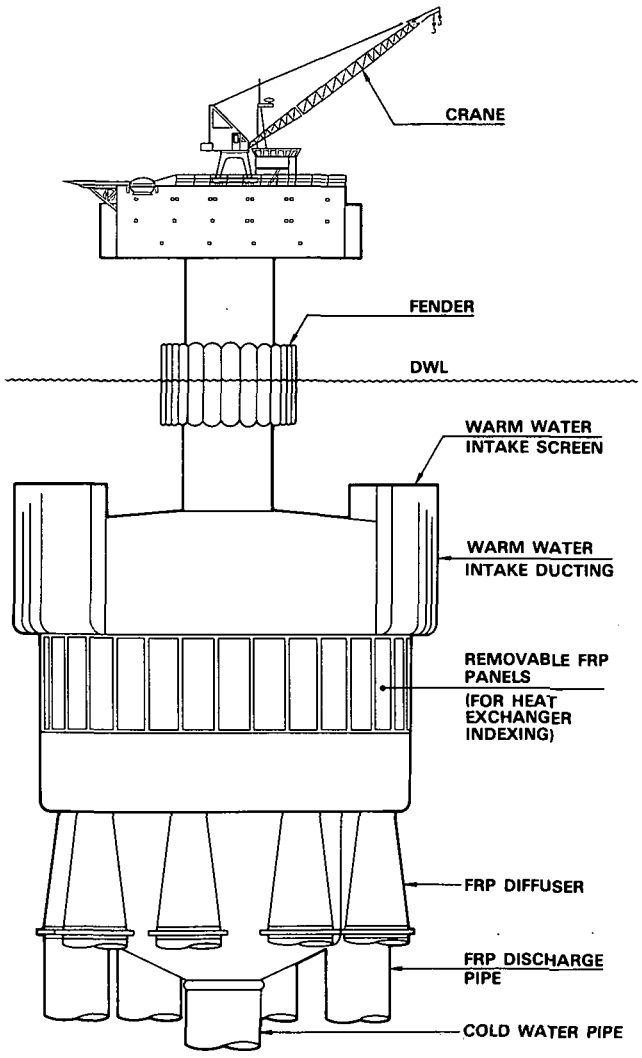
The main spar body is steel. It encloses the turbogenerators, power conditioning equipment, cold water plenum, and platform auxiliaries. The heat exchangers are external to the main body. The pumps for both the cold and warm sea water systems (8 total) are located below the heat exchangers, spaced equally around the outside of the spar body. Discharge tubes extend down from each pump to the 330-foot level. A 35-foot diameter column extends upward from the main body to support the accommodations, control and deckhouse module. The resultant spar has the outward appearance of a cylinder 145 feet in diameter and 206 feet high, with 8 discharge tubes extending below it and the cold water pipe extending 3000 feet down.

The heat exchangers are the Lockheed-Alfa Laval plate type. The radial configuration was chosen due to the required removal of the heat exchanger units once every three years for maintenance. The cold water pipe (CWP), which is 3,000 feet long, conducts the cold water up to the platform and it extends 250 feet below the bottom of the pipe to a dead weight anchor, thus serving to anchor the platform as well. A riser cable that conducts the power from the ship to the sea floor and then to

the shore to tie into the power grid has been designed specifically for the OTEC application taking into account the loads imposed by the mechanical stress as well as the electrical stress.

Barge-Mounted Pilot Plant

There are two versions of the barge-mounted plant: one moored and connected to shore by the electric cable; and one cruising and making a product onboard. The barge is 450 feet overall, has a 175-foot maximum beam and an operating draft of 65 feet. The cold water pipe is attached to the hull by a universal joint. There are no flexible joints in this 3,000-foot long pipe. The power system employs the Lockheed-Alfa Laval heat exchangers. Warm-water pumps in the intake pods supply almost a million cubic feet per minute to the evaporators. Four cold-water pumps supply water to ponds above the condensers. The water flows by gravity through them and is then discharged at the 330-foot level through the discharge pipes. The mooring system must be capable of holding the barge during a 100-year storm. The design must be based on the local conditions where the barge is to be moored and the expected storm conditions. A mooring having ten legs, using embedment anchors, chain and wire rope has been designed.



The power cable is connected to the ship by a gimbal to reduce stress in the cable due to the barge motion. It goes to a stand-off bouy, then to the sea floor, and then to the shore. Both a solid dialectric and an oil-filled, amoured cables are being developed for the OTEC plants. The transmission voltage is 138KV.

The "grazing" pilot plant has a propulsion system, but neither a mooring system nor an electric cable. Guided by information furnished by satellite observation of the sea surface temperature, it seeks the warmest water so that the efficiency of the OTEC plant can be maximized.

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OTEC ISLAND MARKETS

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Island economies are unique in that it is difficult for them to benefit from the economies of scale. They are often spoken of as "pocket markets" which by virtue of their low consumer demand require extended warehousing and storage facilities, large spare parts inventories, and carefully scheduled resupply protocols if they are to successfully interface with systems of high productivity. Concomitantly, endogenous production of goods and services must be artificially limited to avoid oversupply unless an export market is readily available. The net result is higher unit cost for goods and services, than obtains in areas of the world where market site matches the scale of production.

The primary advantage which occurs from this factor of scale is that from time to time endogenous production becomes price competitive with imported products even though it is fundamentally more costly to produce. It is for this reason that many solar energy alternatives look attractive for island economies in advance of their ability to compete on the continent. Unfortunately, pursuit of this short-sighted view can result in developmental strategies which guarantee the economic dependence of island communities.

A more appropriate economic strategy for islands is the development of new products for which island communities have an export potential superior to that of the continental land mass, and the reduction of development costs by utilizing the product during the developmental stage to meet the more limited needs of the island community. A rare opportunity of this kind is provided in the development of the OTEC/ammonia/fuel cell electrical energy system.

The development of this self-sufficient energy system would require one major tropical island for the development of the OTEC ammonia plant, a distribution system, undoubtedly sea-based, to provide optimally scheduled distribution of ammonia to neighboring island (albeit far flung) communities. The major electrical power system of each island would be provided by ammonia fuel cell systems.

Such a development would closely match the economic and energy needs of the Pacific island community. The fuel cell power grid should be developable in units which are small enough to meet the most elemental island needs. Modularity assures growth in increments which provides convenient and inexpensive "spinning reserves." The development of such package power plants which are economic for island systems will lead to the development of package power plants for remote mainland installations and eventually for major urban and industrial grids.

Similarly the OTEC ammonia development will provide ammonia for the initial fuel cell systems whose cost, having been amortized by the development investment, can be provided at a price that makes the ammonia fuel immediately attractive. The successful development of the OTEC ammonia plant can thus be phased with the development of island systems and mainland installations so that growth economies can be optimized and economies of scale can be realized in a timely manner.

It would not be too early to parallel this development with the development of a total ammonia economy for a few of the more remote islands where the costs of multiple fuel delivery are high. Simple modifications to motor vehicles and other internal combustion engines make this a feasible approach.

This total approach in the development of an Ocean-Archipelago Self-Sufficiency Energy System (OASES) will result in an early achievement of energy independence for archipelagic communities and an early realization of the economic energy export of OTEC power.

THE DEVELOPMENT OF OCEAN ENERGY IN THE THIRD WORLD

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Energy problems affect all nations, developed or developing, and consuming or producing. The impacts of energy shortages will continue to increase unless a smooth transition can be made from a reliance on oil and gas to the use of other energy forms. Recognizing this, the United Nations initiated planning for a Conference on New and Renewable Sources of Energy (UNERG). Preparations for the conference are advancing. Mr. Mohamed Habib Gherab, Secretary General of the UNERG conference, recently emphasized that the oceans represent an important source of new and renewable energy, and he underlined the significance of this particular resource for developing countries in particular.

The discussion of the industrialized nations responsibilities for the economic development of the non-industrialized nations has entered a new era. A call to rearrange international relations (by building a new economic order involving a fresh approach to international development) is manifested in the debate. While the developed countries attempt to decide how best to assist the LDCs by defining a new strategy of aid, the developing nations assert their inherent right to participate in the decision making process.

In order to solve these problems, mankind needs a new source of energy that is (1) universally available, (2) is technically appropriate for developing nations, (3) is environmentally acceptable, (4) is manageable, (5) will serve to redistribute capital and (6) will contribute to the interdependence of nations.

Examination of the locations of ocean thermal energy resources reveals how well endowed are the developing countries. Since the ocean thermal resource lies mainly within 20^{o} latitude of the equator, and since most developed countries lie above or below that band, it would appear that the developed countries may have to concentrate on plantship operations in the global commons, or in the use of the territorial seas of their island possessions, but the developing countries have the more direct opportunity to exploit OTEC in their contiguous territorial seas. Since the site is the resource, the exploitation of ocean thermal energy offers a unique developmental opportunity for many Third World nations.

A combination of technical development, innovative finance, and established production capability offers the possibility of OTEC becoming an emerging industry. As a new industry, OTEC would inherit a rich body of legal and institutional precedents from the maritime industry. OTEC operations would be consistent with the Convention on the High Seas and the general principles of current international law which allow a nation to license its citizens to freely conduct activities on the high seas and, more specifically, in its territorial seas.

The financial, legal and institutional needs are interrelated, and it is clear that before investment banks will finance OTEC facilities, a predictable licensing, regulation, and taxation regime must be established. A way to assist the LDCs to establish predictable investment environments is to create two new institutional

modalities under United Nations sponsorship. The first organization would be an enthusiastic advocate of the technology. This group would be affiliated with the development banks and would be concerned mainly with information exchange, the encouragement of national goals and plans, and the promotion of demonstrations, development, joint ventures, and proposals for funding. The second organization would be a clearinghouse for standardization of codes, standards, regulations and policies so OTEC plants could enjoy the same universal acceptance as merchant ships and airplanes. This group would be affiliated with the International Maritime Consultative Organization (IMCO) and function in a similar fashion. It should be noted that United States legislation specifically directs that when multinational OTEC deployment reaches sufficient number and scale, the United States is to initiate, through IMCO or other appropriate international organizations, the negotiation of treaties or conventions to ensure safe and economic operations.

Supporting these considerations is the mutual interest of all nations to contribute to world stability and peace by developing new energy technologies. In essence, anything that will make a nation less susceptible to energy blackmail, will free that nation to act on the basis of its own morals and conscience. A supported and funded program of renewable proliferation is needed to offset the inherently negative policy of nuclear non-proliferation.

A major concern is that the investments of the developing nations will become captive to a new technology controlled and dominated by a single developed nation. There cannot be an international market for OTEC without an international industry, for no nation can afford to commit itself to an OTEC economy unless it has multiple sources of supply of plants, spares, services.

There is also concern about the possibility of creating false expectations, and a potential for exploiting the developing nations by using them as testing grounds for new technologies. There is suspicion that solar energy is being promoted for underdeveloped nations in order to save the remaining oil for the industrialized nations. Not until the developed nations demonstrate viable cost-competitive energy alternatives to imported oil, and commit themselves to a renewable fuel economy, will the developing nations be expected to overcome their suspicions and their interest in the proliferation of nuclear energy.

In summary, the oceans offer a unique energy development opportunity for many Third World nations that are located near the ocean thermal resource. The site is the resource, and the technology is appropriate for many LDCs. During this decade, and with careful planning and management, ocean energy could become commercially available to all nations. The development of OTEC can be created in a manner to reduce the disparities and tensions between nations, and can contribute to world stability and growth.

OTEC BASELOAD POWER COST ASSESSMENTS

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INTRODUCTION

TRW's Defense and Space Systems Group (DSSG), one of several industrial firms involved in the development of economically viable OTEC systems, presents this paper to disclose results of its studies and explain the rationale behind estimated costs. In planning for OTEC, the delivered cost of the system to an owner-operator is critical to the investment decisions. TRW's assessments have been based on this requirement and it is our conclusion that the present cost estimates are usefully accurate given current system requirements and production scenarios.

BACKGROUND

TRW has been involved in OTEC development since 1974 (see Table 1). In an initial project under NSF sponsorship, the technical and economic feasibility of OTEC as a baseload power supply was assessed. It was concluded that OTEC systems would be competitive with oil-fired systems whose feedstock cost was $20 per barrel (1975 dollars). Since then, system cost and design models have been refined by TRW and others, and confidence in projections improved.

RESULTS

Investigators' cost projections for OTEC systems vary depending on assumptions made for the technology and for financing costs, inflation rates, and amortization of facilities. Cost estimates in this paper are in constant 1980 dollars, and include total capital cost of the plant as delivered to an owner-operator. They are higher than current estimates by others in which other base years or financial considerations are used. It is not our intent to defend the least cost of an OTEC system technologically achievable, but to use nominal costs for evaluation of potential economics given plausible sale prices of OTEC power. We conclude that OTEC appears competitive with existing (oil-fired) energy conversion systems in the U.S. island markets.

Primary elements of an OTEC baseload system are the power unit, the platform and the power transmission equipment. The power unit design is the most studied since it is the heart of OTEC and represents a major portion of the total costs. These units have evolved to a near optimum size of 10 MWe due to existing production capabilities for heat exchangers. The cost of mass produced power units are shown in Table 2. The primary difference between the two designs is that PSD I is based on titanium fluted tubes in a vertical shell, whereas PSD II is based on a stainless steel shell-less plate tube design. The platform consists of the hull, cold and warm water piping and pumps, and stationkeeping equipment. This element has been shown to be sensitive to scale, with larger hulls

TABLE 1 TRW OTEC Projects Funded by DOE

PERIOD OF PERFORMANCE	PROJECT TITLE	CONTENT	CONCEPT
JUL 74-AUG 75	RESEARCH ON 400 ENGINEERING EVALUATION AND A TEST PROGRAM	CONCEPTUAL DESIGN OF A 400 MWe OTEC PLANT & PROGRAM DEVELOPMENT PLAN	
NOV 75-AUG 76	OTEC TEST FACILITY STUDY PROGRAM	TEST FACILITIES DESIGN & COST (ALSO) STUDIES ON ENERGY UTILIZATION	
JUL 77-JUN 80	1 MWe HEAT EXCHANGERS FOR OTEC	DESIGN & FAB OF LARGE EVAPORATOR & CONDENSER PLUS AUXILIARIES & INSTRUMENTATION	
AUG 77-DEC 79	POWER SYSTEM DEVELOPMENT I	DESIGN OF COMMERCIAL-SCALE OTEC POWER SYSTEM BASED ON ADVANCED (VERTICAL FALLING FILM) HEAT EXCHANGERS	
OCT 78-APR 80	OTEC-1 EARLY OCEAN TEST PROGRAM	DESIGN OTEC POWER PLANT; DESIGN & BUILD INSTRUMENTATION & CONTROL VAN	
SEP 78-NOV 79	POWER SYSTEM DEVELOPMENT II	DESIGN OF COMMERCIAL-SCALE OTEC POWER SYSTEM BASED ON ADVANCED (PLATE TYPE) HEAT EXCHANGERS	
SEP 78-AUG 80	COLD WATER PIPE • DESIGN • 2-D MODELLING • SUB-SCALE EXPERIMENTS	DESIGN, ANALYSES AND TEST OF COLD WATER PIPE CONCEPTS	
OCT 78-MAR 80	ENERGY UTILIZATION	FEASIBILITY STUDY ON USE OF OTEC IN ALUMINUM REFINING	

TABLE 2 Power Plant Costs

	PSD I[1]	PSD II[2]
Heat Exchangers	1354	764
Turbine/Generator	210	253
Ammonia Loop	223	264
Other Support	250	213
Total	2037	1494

being significantly less costly than smaller ones, and to the power system configurations. TRW's assessments for the cost of this element are shown in Table 3. The third element, the electric transmission equipment, is highly dependent on the location of the plant with both depth and distance to shore being critical variables. As a basis of evaluating the potential for OTEC baseload systems, an average distance of 100 miles with a DC system and a maximum depth of 4000 feet have been assumed. The cost of this element is shown in Table 4. Combining these three elements results in a total OTEC system cost as shown in Table 5.

TABLE 3 OTEC Platform Costs

	400 MWe Size	
	PSD I	PSD II
Hull	470	840
Cold Water Pipe	190	180
Stationkeeping	120	120
Outfitting	200	200
Pumps/Ducts	220	220
Deployment	150	150
Total	1350	1720

TABLE 4 Electrical Transmission

Cable	400
Riser	140
Shore Substation	50
Total	590

TABLE 5 OTEC Baseload System Costs

	400 MWe Size	
	PSD I	PSD II
Power Unit	2037	1494
Platform	1350	1720
Transmission	590	590
Total	3977	3804

Translating these system costs (C/KW) into delivered cost of OTEC generated electricity is dependent upon the utility fixed charge rates (FCR), the capacity factor (FA), and cost of maintenance (COM) as follows:

$$\text{Busbar Cost (mills/KW-hr)} = \frac{(\text{C/KW} \times 1000)\ (\text{FCR})}{(\text{FA})\ (8760\ \text{hrs/year})} + \text{COM}$$

For a cost of maintenance of 4 mills/KW-hr and an availability factor of 0.9, the cost at the tie to the grid will range from 58 mills for a public utility with a fixed charge rate of 0.1125, to 96 mills for a private utility with a fixed charge rate of 0.1920, assuming a system cost of $3,800/KWe. A recent Rand sensitivity study[3] indicated that there are no significantly dominant OTEC construction activities which could dramatically alter the costs of a plant. Thus, our conclusion is that OTEC cost projections can be made with adequate confidence for budgetary and planning purposes, and for comparisons of system and subsystem alternatives.

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ARTIFICIAL UPWELLING IN THE CARIBBEAN

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It was in 1881 that d'Arsonval proposed to utilize the temperature differential in the tropical ocean to run a heat engine and generate electrical power (1). Since that time, two significant developments have taken place on the Caribbean islands to utilize this regions' most abundant resources: the sun and the sea.

In 1930 a French engineer, George Claude (2) constructed an open cycle OTEC plant at Matanzas Bay on the north shore of Cuba with a capacity of 22 kilowatt output of electrical power. Claude obtained a 14°C thermal differential by pumping seven hundred meter deep water through a 1.6 meter diameter pipe extending about 2 kilometers off shore. The plant's operation was short lived because of trouble with the cold water pipeline, but Claude demonstrated that the process was technically feasible.

In view of the recent rise in oil prices, and since most of the Caribbean island nations are entirely dependent on imported oil for their energy production, considerable interest in the utilization of the sea thermal power difference exists in the area. Indeed, 16 Caribbean nations have 1,000 meter deep ocean water within less than 5 kilometers from their shores so that they could install both shore-based or near-shore floating OTEC plants for their power production. These nations are Belize, Bonaire, Cuba, Curacao, Dominica, Grenadine Islands, Grenada, Guadeloupe, Honduras, Martinique, Mexico, Commonwealth of Puerto Rico, St. Lucia, St. Vincent, U. S. Virgin Islands, and Venezuela. The temperature differential between the surface water and the deep ocean water throughout the Caribbean is emminently suitable for OTEC systems.

In a recent study, Jesus A. Sanchez (3) has compared the OTEC alternative for Puerto Rico versus coal, oil and nuclear power. Mr. Sanchez concludes that it appears that nuclear power generation would be the most economical choice particularly for the period 1989-90 to 2010. OTEC is the closest competitor. Although OTEC does not consume fuel, its high investment cost makes the difference between the OTEC and nuclear options.

This high cost of sea thermal power generation incited Roels and his colleagues (4) to examine the possibility of utilizing not only the cold temperature of the deep ocean water for ΔT applications but to utilize also the relatively high nutrient content (compared to surface water in the tropical ocean) of the deep water in a mariculture system.

Again, this group of investigators chose a Caribbean location, the north shore of the island of St. Croix, because this site at 17° North is well within the tropical belt, and 1,000 meter deep water is no more than 1 mile off shore. The initial concept of these investigators was to utilize these deep ocean water nutrients in a managed marine food chain to produce valuable products such as oysters, clams, scallops, and shrimp.

They established a pilot project on the north shore of St. Croix where three deep water pipelines were installed to a depth of 870 meters in the ocean. These pipelines provided for 7-1/2 years an uninterrupted flow of deep sea water to shore based ponds where algae were grown. The algae were fed continuously to higher marine organisms. Oysters, clams, scallops, brine shrimp and penaeid shrimp were produced successfully in this system.

An earlier analysis of the system indicated that other applications of the ΔT might be economically more interesting than power generation. Desalination and air conditioning based on the deep sea water are economically more attractive than power generation (5). The mariculture component of such an artificial upwelling system would yield far more dollars in gross sales volume per unit deep sea water pumped than either the desalination or the power generation (6).

At the present time some industrial groups are investigating the possibility of establishing Artificial Upwelling systems in the Caribbean. It is believed that the sea and the sun can make significant contributions to the development of the Caribbean nations through artificial upwelling.

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ECONOMICS OF OTEC IN THE PACIFIC

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This paper analyzes the economic feasibility and potential economic impact of OTEC in the Pacific island countries. The cost of OTEC plant construction, operation and maintenance compared with the potential economic benefits is examined in relation to:

a) Electrical power generation to meet present and expected future energy demands, to reduce reliance on imported oil and possibly achieve energy self-sufficiency. The Pacific island countries presently rely almost entirely on imported oil for their energy requirements. The quadrupling of oil prices in 1973-4 and the accelerated price increases of 1979 have resulted in enormous debt burdens, making it vital to develop indigenous energy sources.

b) Increased energy production to stimulate economic growth and lessen the external debt, taking advantage of domestic resources or strategic locations for industrial processing facilities. Previously the major impediment to the development of local industries was the unavailability of energy supplies, which was due to the high investment costs of energy facilities. A beneficial effect of the increased oil price has been to make it more economic to develop alternative energy sources, such as OTEC. Small-scale OTEC plants in the 1 - 10 MW range in remote islands could significantly affect local economies,both as a source of electricity and as a means of developing energy-intensive industries locally. An example is the processing of bauxite to alumina and aluminum, where major transport economies could be realized if the bulkier alumina could be processed locally,using OTEC-produced energy, into aluminum and then exported. Other small-scale industries could also be developed.

c) Production of ammonia for fertilizer. The world-wide shortage of fertilizer has an adverse effect on the development of local agriculture. The particular beneficial effect of OTEC will be to stabilize supply of ammonia, minimize transportation costs and achieve local independence of supplies. The relative prices of fertilizer costs and food grain prices will have to maintain a positive benefit/cost relationship and care will have to be taken to avoid over-production and resulting deflation in world market prices,but OTEC may increase the potential for export of ammonia as well as domestic use.

d) Production of fresh water. Studies have suggested that

the energy-mariculture-fresh water approach may be economically beneficial. Both increased fisheries production and aquaculture are potential benefits, together with the advantages of a fresh water supply in deficient areas.

e) Indirect economic benefits include those deriving from the transfer of technology, training of local personnel, oceanographic and environmental exploration incidental to OTEC development leading to increased knowledge of local ocean mineral and fisheries resources, ocean currents and other benefits.

POLITICAL FACTORS IN ISLAND OTEC DEVELOPMENT

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The technical and economic potential for OTEC implementation in Pacific Island waters has been described in other papers. This paper discusses political factors which are significant either as impediments to OTEC implementation, and thus the realization of OTEC's potential, or as potential effects of changed conditions resulting from OTEC implementation. The rationale presupposes that OTEC would provide electric power and fuels to the Pacific Island states themselves; would provide marketable fuels and energy-intensive products such as aluminum or ammonia for export; and, through the magnitude of these markets, would have the potential for substantially reducing the demand for petroleum. There are three fundamental contexts from which to view the political aspects of OTEC implementation: that of the Pacific Island states themselves; the impact on extra-regional states; and the impact on the international political system.

The Pacific Island States. The island states are among the most heavily affected by heavy dependence on oil, imported technology, and foreign capital. They have a vital interest in successful OTEC implementation. Unfortunately the intensity of their need for OTEC's benefits does not automatically reduce typical institutional barriers to implementation of new technology. Small island polities are not necessarily better able to traverse difficult decision-making processes.

Domestic island power grid demands are typically on the order of 10 MW; and in the short run, OTEC power, whether brought ashore from cables or in the form of transportable fuels, will displace capital investment in fossil fuel plants. This invalidation of petroleum-based capital investments has obvious political and legal implications; but there are further considerations: legal requirements for local control and home equity, income repatriation, and the like, which may also inhibit private investments. Governmental participation, aid from extra-regional nations and international financial institutions would be indicated in such cases. The choice of these methods is necessarily a political one. Nationalistic sensitivities toward aid and the terms and manner of its giving; questions concerning the division of such aid among candidate states; and the relative advantages states may achieve over others are major political costs of extra-regional aid.

The most effective implementation of first-phase OTEC plants will therefore require resolution of these problem areas through traditional means, ranging from workshops and study groups for exchange of information and ideas, to formalized agreements such as contracts and treaties. Such methods must address as primary concerns the complex new provisions of the law of the sea, specifically the 200-mile exclusive economic zone, environmental obligations, and questions of claims to the resource on the high seas.

Extra-regional factors. Second phase and third phase OTEC implementation would involve relocation of energy-intensive industries to sources of OTEC power, and the use of energy-intensive industrial processes in the "grazing ship" mode either on the high seas or within 200-mile economic zones. The likelihood of the latter can be judged from reference to maps showing the extent of coverage of 200-mile zones in

the thermal belt of the Pacific. Coastal state jurisdiction over operation of OTEC plants may be claimed in waters above national continental shelves. Were this the case, national jurisdiction over OTEC would extend as far as 350 miles from the shore. There are relatively small areas of high seas jurisdiction between the zones of the Pacific Forum states; and for fisheries purposes, at least, the possibility exists that these states will attempt to assert jurisdiction over the fisheries resources of these areas by making their licensing for access to economic zones contingent on recognition of limited high seas jurisdiction. A similar tactic may be employed in regard to OTEC.

It is not axiomatically true, then, that extra-regional states will have unimpeded access to the thermal resources of the Pacific. Craven's Law relating to the inevitability of expansion of coastal state claims therefore finds another potential application. The engineering and cost advantages of scale in OTEC plants may, however, provide strong impetus to a mutually advantageous interactive relationship between regional and extra-regional states. In second- and third-phase implementation, in which storable fuels and the use of ammonia fuel cells may become a viable factor for the small economies of the island states, cooperative arrangements with OTEC exporting states may be achieved. Indeed, optimistic analysts may consider such arrangements probable, harking back to the Phoenician character of ocean affairs and their great adaptability to fluid economic and political relationships.

Whether these relationships are predominantly cooperative or conflicting, then, will depend more on the underlying factors of community, nationalism, and willingness to interpret self-interest in a liberal manner, than on the intrinsic character of OTEC as a technology. A strong perception of need for the resources of the thermal belt on the part of the energy consuming extra-regional states will, of course, provide the basis for formalized relationships with island states, which will thereby achieve a vast improvement in influence and power potential in the world polity.

The International Political System. The energy crisis has focused massive political conflict on the Middle East. There is a high probability of interruption of traffic through the Hormuz Strait, through which flows 40% of the world's petroleum. The consequences for most states of the world are such that the probability of war would be greatly increased thereby. Phase four OTEC implementation contemplates substantial displacement of fossil fuels with ammonia or hydrogen for aircraft, vehicles, and similar purposes. This phase would complete a lengthy process of removing political pressure from the Persian Gulf. The process of OTEC implementation in the Pacific Island states is integral to the general interests of the international political system in preservation of peace and maintenance of strong security relationships. Further, regional arrangements for OTEC implementation in the case of island states will be precedential for similar legal, diplomatic, and political cases elsewhere, thus reversing the more usual case in which European or North American usage is employed in the Third World.

The process of OTEC implementation, in the context of pressing global requirements for replacement of oil with other energy sources, may be viewed as a massive societal challenge and response, in which the major question is whether crises and violence are to be avoided, and in which the coping institutions are the relevant national, regional, and international political systems. These systems are charged with the decisions which will be crucial to successful implementation of OTEC in the island states.

OTEC FOR THE PACIFIC ISLANDS - A JAPANESE PERSPECTIVE

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Japan is one of the island countries in the Pacific, with poor energy resources. Japanese OTEC R/D in 1970s is reviewed. These technologies can be useful for the Pacific Islands. An OTEC-Mariculture complex is proposed, which would enable a small OTEC power plant to operate as competitively as a conventional power plant.

Introduction: Japan is one of the island countries in the Pacific Ocean. These countries, with a few exceptions, have poor domestic energy resources which are essential for the economic development and for the improvement of the standard of living in these countries. However these island countries are blessed with warm sea surrounding them. Average of monthly ΔT's between the water at the surface and the water at the depth of 1000 meters is larger than 18°C in the zone between the latitudes of about 30 degrees North and about 25 degrees South. OTEC development seems to be substantially important for these Pacific island countries. To make OTEC commercially available in the future, a feasibility study should be made at first in respective countries. It should cover technical, economical, social and environmental aspects. Then the project planning can be prepared using the results of the study.

OTEC Research and Development in Japan: Energy consumption in Japan is large. That is the second highest in the free world next only to the U.S.A. The energy import ratio amounts to 88% of the total consumption. The land area of Japan is small, but it is surrounded by an extensive ocean, mostly warm, and the "Kuroshio", one of the largest sea currents, brings a large amount of thermal energy from the tropical zone.

The study of OTEC in Japan was started in 1970. In April 1974, which is just after the first oil shock, an OTEC feasibility study was started by a committee in the Sunshine Project, which is the national project to develop new energy technologies, other than nuclear energy; the latter had been developed since 1957. Also an experimental research on OTEC was started in 1974 at the Electrotechnical Laboratory, a branch of MITI, and at the Science and Engineering Faculty of Saga University in Saga. In the industrial circle, Tokyo Electric Power Service Co. (TEPSCO) started their design study of land-based OTEC power plants, somewhat earlier than those mentioned above.

In November 1979, both the Ocean Development Council and Industrial Science and Technology Council have adopted OTEC development as one of the alternate energy development targets of Japan. This was authorized by the Prime Minister in July 1980. This program includes the development of a 1 MW ocean-based OTEC experimental plant which will be completed in March 1984 and a 10 MW OTEC pilot plant which will be constructed during the period from 1985 to 1990.

The first ship-borne OTEC experiment was undertaken in October 1979 on the Japan Sea, by Saga University under the direction of Dr. Uehara and with the cooperation of several industrial companies, including Tobishima Construction Company and Toshiba Corporation who coordinate the ocean- and power-systems subgroups.

Two large power companies in Japan, Tokyo and Kyushu Power Companies have started company-funded projects to construct land-based 100 and 50 kW experimental OTEC wer plants respectively which are scheduled to be completed in 1981. Following eir successful performance, they may proceed into the first step of OTEC commercial plants for the island markets.

Development of OTEC key components was undertaken by several manufacturing companies including power equipment, shipbuilding and construction fields, and some new products have already appeared on the market.

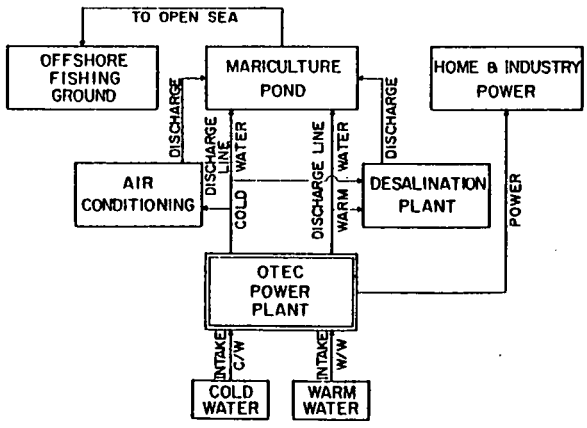
OTEC Power Plant for Japan: To estimate the economical and technical feasibility of OTEC in Japan as a new energy to substitute the imported oil, the conceptual designs of several types of 100 MW OTEC commercial power plants were made by the OTEC committee in the Sunshine Project between 1975 and 1978. In the 1978 study, two model sites, Osumi and Toyama, representing the Pacific Ocean side and the Japan Sea side respectively, were selected. Sea temperatures of both sides show big difference. The underwater temperature in the Japan Sea is very low. It goes down to below 1°C at the depth of 400 meter. The surface temperature in the winter is about 10°C, compared with about 26°C in the summer. The sea temperature of the Pacific Ocean side shows quite a different profile. The influence of typhoons is generally not so severe in Toyama as in Osumi. Optimization to get minimum unit construction cost per kilowatt output at the busbar, of the conceptual design of 100 MW OTEC power plants, was made at both Osumi and Toyama. The results were ¥790,000/kW and ¥593,000/kW respectively. Cold water pipe length was 790 m in Osumi and 370 m in Toyama. The unit power cost at the busbar in both sites incidentally amounts to about the same price of 13 Yen/kWh (∿ 60 Mills/kWh), because the lower construction cost in Toyama is offset by the effect of the fewer operating days there than in Osumi.

OTEC Complex for Pacific Islands: For the Pacific Island countries located in the lower latitude, ΔT's, the differences between the surface and the under water temperature, are mostly bigger than in Japan throughout the year. Bigger ΔT's will contribute to reduce the power cost of the OTEC plant. However many islands may wish to have smaller OTEC plants than 100 MW mentioned above. But the unit power cost of smaller plants will be much higher than that of bigger ones.

There seems to be two ways to solve the cost problem of small OTEC. One is to expand the island economy by introducing new profitable industries, which would consume the generated power of the large OTEC power plant. The other is to find a system which may be called OTEC Complex; it not only generates power but also produces other profitable products or means utilizing enormous volume of the water discharged from the OTEC plant. If the plant can sell the discharged water, the unit power cost can surely be reduced.

In May 1972 the author proposed an example of such a system, at the fifth General Meeting of the Pacific Basin Economic Council held in New Zealand. The concept of this system is shown in Fig. 1. It may be called OTEC-Mariculture Complex. Requirements for the site selection of this system may be (1) good ΔT profile, (2) steep bottom profile at the open sea side of shore-based OTEC power plant, (3) that a lagoon or a narrow-mouthed bay for mariculture is located not far from the power plant, so that the nutritious discharged water from the plant should be used for mariculture, and (4) social systems which can sustain the system's activity, for example, an air port, for the quick export of the marine products, and for receiving visitors to the islands.

FIGURE 1 OTEC-MARICULTURE COMPLEX



Practically, quantitative feasibility study of an OTEC-Mariculture Complex should be undertaken for the specific island. The size of the power plant, the kinds of the market-competitive products, and the total system design should be determined. If an excellent result is obtained by the feasibility study, this system can proceed into the development stage.

GRAZING OTEC PLANTSHIPS TECHNICAL STATUS POTENTIAL PRODUCTS AND COSTS

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OTEC plantships use the electric power generated on board to manufacture products which can be shipped to the U.S. (or other countries), to replace oil or products made from oil. OTEC plantships could utilize the total thermal resource of the tropical oceans to produce estimated total power of ~10,000 gigawatts. Plantship costs are lower than for moored OTEC facilities because mooring and cable costs are eliminated and net power output (proportional to ΔT^3) is significantly higher.

Technical Status. Mini OTEC operation in August to December 1979 fully confirmed predicted values of OTEC power output in ocean operation, demonstrated successful operation of a cold water pipe 2200 ft long and showed that biofouling was completely prevented by 1 ppm addition of chlorine. OTEC-1, a floating facility to test heat exchangers of 1 MW_e capacity is now deployed. Tests show that 1 ppm chlorine for 15 min/day is effective for control of biofouling. This amount is far below EPA limits. Ultrasonic radiation at 1 watt/cm^2 is effective in removing slime accumulations, and higher intensities can remove more tenacious organisms without damage to the heat exchanger material. Thus practical solutions are available for the biofouling problem. Tests indicate that low cost aluminum heat exchangers will have operating life of 15 years or more. Titanium and Al-6X stainless steel are qualified for 30 year life, at considerably higher cost. Baseline designs have been finished of a complete 40 MW OTEC pilot/demo plantship, including power plants, concrete platform and cold water pipe and flexible platform connection, and synthesis plant to produce 43,000 tons/year of ammonia. Model tests at sea with a 5 ft diameter 500 ft long rigid steel pipe, and 350 ft jointed pipe confirmed predicted dynamic behavior of the platform-CWP system. Tests to destruction of a jointed section of a concrete 1/3 scale model of the 30 ft concrete cold water pipe (CWP) were successfully completed, and showed that failure occurred at 130% of the maximum stress expected in a "100 year storm" in the Atlantic operating area. Tests of a 1/30 scale model of the pilot/demo plantship with CWP and heat exchanger simulation in the Offshore Technology Corp. model-basin showed that the design was suitable for the maximum storm conditions. Altogether the tests, engineering analyses and design work show that the OTEC program is now ready for the next phase: construction of the 40 MW pilot/demo plantship.

Energy Products. Analyses show that electric power generated at the OTEC plantship may be used onboard to produce hydrogen, ammonia, methyl alcohol, liquid natural gas, aluminum, alloys prepared in electric furnaces, semiconductor materials, and refining of manganese nodules. Reviews of manufacturing requirements, potential costs vs alternative methods of preparation; transport, handling and distribution requirements, and market demand show that ammonia is the best candidate for initial OTEC production. It can be made on-board from H_2 produced by water electrolysis and nitrogen separated from the air, wherever the grazing plantship is operating, and OTEC ammonia can replace ammonia made from natural gas in the United States. Ammonia manufacture in 1979 consumed 700 billion cubic feet of natural gas, equivalent in energy to 120 million barrels of oil. Projected new demand for ammonia by 1990 will be 13 million tons/year (one ton of ammonia requires 35,000 ft^3 of

natural gas in the present process) which could be supplied by OTEC after 1990 at delivered costs lower than the cost of ammonia from decontrolled natural gas or coal. Essentially the same process equipment used for ammonia synthesis may be used to form methyl alcohol if the catalyst is changed and CO_2 replaces N_2 as input gas. For this process CO_2 must be transported to the plantship, but with some modification of the ammonia tanker carbon dioxide can be carried to the ship in the same vessels that are used to transport the methyl alcohol product to shore. Methane may be prepared on the OTEC plantship by dehydration of methyl alcohol, or directly from H_2 and CO_2, and liquified for shipment in LNG tankers. Hydrogen, the primary product of water electrolysis may also be liquified for shipment in special tankers. However, unless a large market develops for liquid hydrogen, per se,which may eventuate for aircraft use,it is more economical to transport and store hydrogen via liquid ammonia than as liquid hydrogen.

With the phasing out of favored rates for aluminum producers by the electric utilities, OTEC may offer the lowest cost power in the 1990's, and aluminum producers are now considering this possibility. A feature of their future plans is the use of a new refining process developed by Alcoa based on $AlCl_3$ offers important advantages in power consumption and plant size, and is tolerant of ship motions. OTEC plantships offer an attractive platform for deep ocean mining operations in recovering and refining of manganese nodules, which can provide a future source of copper, cobalt, nickel and manganese. Investigation of this possibility is still in a preliminary phase. Manufacture of semi conductor materials and of special alloys on OTEC plantships do not appear commercially attractive.

Costs. Since OTEC has no fuel costs, and O&M costs are expected to be small the cost of OTEC power and energy products will be determined by the capital investment required for construction of the OTEC plantships and moored OTEC power plant facilities. Completion of the baseline system designs has made it possible to develop cost estimates that are based on manufacturers quotations for "off-the-shelf" components which account for 60-70% of the total cost, and on engineering designs of the platform, cold water pipe and heat exchangers. Therefore, although firm costs must await the results of pilot/demo plants construction, it is believed that reasonable confidence can be placed in the present estimates. These are presented in Table I for the 40 MW pilot/demo of the OTEC ammonia plantship, and for the first, second and eighth commercial ships. (Product cost 8th ship 21% profit & cont'gy)

TABLE I. ESTIMATED COSTS OF OTEC PLANTS AND PLANTSHIPS AND PRODUCTS

SITE	HAWAII (moored)				PUERTO RICO				GULF OF MEXICO			GRAZING (ATL-1, PAC-2)			
Δ T °F (Av)	38.5				40.2				38.0			43			
PLANT TYPE	Pilot/Demo	Commercial Size			Pilot/Demo	Commercial Size			Commercial Size			Pilot/Demo	Commercial Size		
NET POWER (AV) MW	30.0	235			34.3	266			217			43	325		
CAPITAL INVESTMENT $M		1st	2nd	8th		1st	2nd	8th	1st	2nd	8th		1st	2nd	8th
0% (profit & contingency)	190	670	570	490	190	670	570	490	750	680	590	160	685	600	510
30% (profit & contingency)	240	870	140	630	240	870	740	630	970	890	770	205	890	780	665
$/KW															
0% (profit & contingency)	6335	2850	2430	2085	5540	2520	2145	1840	3455	3135	2720	3720	2110	1845	1570
30% (profit & contingency)	8000	3700	3150	2680	7000	3270	2780	2370	4470	4100	3550	4765	2740	2400	2045

PRODUCT	AMMONIA (liq.)	HYDROGEN (liq.)	METHYL ALCOHOL	METHANE (liq.)	ELECTRIC POWER
COST AT PLANTSHIP $/TON	186	1325	205	558	
FEEDSTOCK $/TON	-	-	34	68	via OTEC ammonia and fuel cell
SHIPPING $/TON	16	160	-	-	
DELIVERED COST $/TON AT COAST	204	1485	239	626	73 mills/KWH

CLOSED POWER CYCLE DEVELOPMENT

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BACKGROUND

The OTEC community has consistently demonstrated the technical feasibility and practicality of positive net power generation with both closed and open cycle power systems. Further, there is general agreement that a closed cycle ammonia plant can be built now. The economics are favorable for this plant, where appropriately sited, as compared to an oil fired utility electric generating plant. However, the large first cost and the lack of a sizeable demonstration plant preclude serious interest from the necessarily conservative power generation community. Therefore, the private OTEC community requires enabling legislation, economic encouragement in the form of tax write-offs, etc. and generally friendly relations with government at all levels in order to implement the initial demonstration sized closed cycle ammonia plant.

ABSTRACT

It is shown that designing an ammonia closed cycle OTEC plant to a given set of site specific data with the dual objectives of:

- PLANT FIRST COST/EFFICIENCY
- PLANT RELIABILITY/AVAILABILITY

requires a highly knowledgeable, experienced approach to SYSTEMS ANALYSIS and DESIGN. Considerations of maximizing plant power in response to seasonal variations in surface water temperature as well as optimization of the total plant (including cold water pipe, mooring, transmission cable and hull) rather than just the power system must be addressed.

While earlier OTEC studies, with 80°F surface water and 40°F cooling water from the ocean depths, served the very useful purpose of competitively generating a data base for power system and component design development - this somewhat simplistic approach must now give way to site-specific studies that result in the most efficient and unique plant designs for specific environmental conditions.

Procedures for developing the required total system analytic design optimization programs are discussed. These programs are used to (1) determine proper assignment of temperature differences to the principal components - e.g. evaporator, turbine, condenser, (2) determine optimum velocities of working fluid and size turbine and heat exchangers, and (3) determine optimum diameter of sea water pipes and velocity of sea water flows. Parametric investigations with these programs are effective in evaluating the total system cost effectiveness of options like heat exchanger enhancements, turbine exhaust diffuser geometries, etc. Also, design optimization programs are effective in conducting sensitivity analysis to determine design margin data bases for parallel effort in subsystem or component design analysis.

Creation of the analytic performance programs to simulate off-design and transient operation conditions are dealt with. These performance programs are required to determine specifications of subsystem machinery (type of seawater pumps, capacity and type of recirculating pumps, minimum hotwell volumes, sizes of connecting piping as well as entire control system) and power system response to perturbations such as various biofouling levels, load dumps, surface water temperature variations, etc. These investigations with dynamic performance programs are a separate and distinct mode of inquiry from the parametric investigations with the power system optimization programs.

All of these investigations collectively provide data to further iterate the OTEC plant design to aggressively pursue the initially stated objectives;

- First Cost/Efficiency
- Reliability/Availability

for each varying set of site-specific data.

This basically analytic process requires the guidance of proper constraints in the form of manufacturing limitations, material and process costs, characteristic performance functions of all major components, etc. OTEC programs to date have developed a wealth of information on closed cycle components, much of which has and continues to be verified with current hardware test programs. The utilization of this data is provided for in the modular analytical analysis programs described to maintain the very latest state-of-the-art data base and the required conservative approach to design that the electric utility customer requires.

THE PROMISE AND THE CHALLENGE OF ALTERNATE OCEAN ENERGY CONVERSION SYSTEMS

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While the engineering emphasis of the U.S. program in ocean energy is directed at demonstration in large scale and in open ocean of an OTEC power plant using closed Rankine cycle energy conversion hardware, there is a significant ongoing advanced research and development program which has as an objective the development of alternate power cycles which have the potential for improved cost effectiveness for power from the sea. This program has been structured along the lines of alternative cycles for conversion of the thermal resource and, secondly, systems for conversion of alternative ocean energy resources such as waves, currents, or salinity gradients.

The alternative thermal cycles work can be classified into two groups:

- Claude (open) cycle for which subsystem development has been initiated.
- Advanced concepts whose potential for technical and economic feasibility is being evaluated.

In the middle of FY1979, a feasibility system study was completed by the Westinghouse Corporation in which the potential for open cycle OTEC as a cost effective alternative to the closed cycle was shown. In addition to the potential for lower cost, the open cycle showed potential advantages in terms of minimizing the risk due to corrosion and biofouling of metal heat exchangers which are required in the closed cycle configurations. A technology development program for subsystem development was initiated in fiscal year 1980. This program has as an objective the development of detailed experimental data and analysis on which basis a definitive assessment of this concept can be made. This technology development program will culminate in the testing of a subscale one megawatt open cycle experiment in the middle of FY1984. By developing this technology in this timeframe it will be possible, to offer an alternative to the closed cycle technology.

The advanced thermal cycles, as typified by mist lift and foam lift cycles are undergoing evaluation and study and remain as viable power cycle options. The criteria by which all power cycles in the conceptual evaluation stage are evaluated, are that they must be technically feasible and that they have the potential for economic feasibility. The bands of uncertainty for both of these areas are reduced with each succeeding research phase and the cycles are constantly being re-evaluated as to their potential when compared with other new and innovative power cycle designs. Each of these conceptual designs has been economically evaluated by a first order approximation and reported to have the potential to significantly reduce the cost of energy extracted from the sea.

The main program objective for each of these advanced power cycles is to demonstrate positive work in a steady state mode of operation at typical OTEC conditions n relatively small laboratory-scale experiments. When this evaluation is favorable nd can be made with great confidence, a decision to proceed to subsystem development and the solution of pressing engineering problems can be made.

Alternate thermal cycle conceptual designs will be evaluated on a comparative basis in FY1982 in terms of technical and economical factors. Other possible options such as thermoelectric OTEC and jet condensing OTEC will be factored into this process. Further consideration of these options would have to be preceded with some basic feasibility research since their potential depends on an extension of present technology.

The main thrust of past wave energy research has occurred in Europe and primarily in the countries which have access to the formidable North Atlantic resource. The emphasis on wave energy is reinforced in these countries by the fact that more conventional forms of solar energy are less attractive as alternate energy sources because of climate. The more recent interest in the U.S. is prompted, in part, by the fact that wave energy represents an energy alternative to geographic locations which derive a lesser benefit from use of direct solar. The Pacific Northwest and, to a lesser extent, the U.S. Atlantic Coast are good potential wave energy sites. The promise of wave energy is that it is a more concentrated and persistant energy source than other solar alternatives (at 50 KW/M of wavefront). This arises out of the fact that waves are wind generated and the major component of the resource results from weather long distances away from the collection point and is the result of many square miles of sea-air interface. The historic perspective of past development activity is that extraction/conversion efficiencies of over 80% have been achieved. It is possible that wave focusing might allow efficiencies in excess of 100% when efficiency is defined in terms of the energy normally intercepted by the "footprint" of the device in the sea. This possibility improves the potential for wave energy to be a cost effective source of energy.

The challenge of the wave program is to achieve the costs which make this potential a reality. Ocean engineering problems particularly in the areas of mooring, storm survival, and power transmission have conspired to make systems costs unacceptable to date. The U.S. program is presently structured to

- develop wave focusing
- define concepts within a power delivery system context
- select the most promising wave extraction concepts

Through this process we plan to assess the potential for economic feasibility in wave energy and develop that potential, should it exist, into operating at-sea pilot plants suitable for commercialization.

The energy available in ocean currents such as the Gulf Stream is more limited geographically and in amount than other ocean energy sources. However, the tens of gigawatts potential for the Southeast Power Grid area merits the development of data which will support the definitive evaluation of this concept. Only one approach is currently under serious consideration, and that involves the submergence of a ducted axial flow turbine in areas of significant natural water flow such as exists at the Miami-Bimini transect of the Gulf Stream. A sixty meter diameter turbine in this location could deliver over 4 MW of electrical power into the utility grid. Designs exist which appear to offer the potential costs in the order of $1275/peak kw. This low cost plus the opportunity to do significant at-sea experiments at small scale make this technique a prime candidate for successful development. The key issues being addressed are (1) an evaluation of the amount of the resource and the amount which can be successfully extracted, (2) the actual cos of the system/hardware, and (3) survival, maintenance, and other operational

characteristics. It should be possible to make decisions with regard to subsystem development during FY1982.

An alternate ocean resource of great magnitude is the chemical potential between seawater and river water in the nation's estuaries. Two approaches for obtaining power from salinity gradients are being studied: (1) osmotic exchange against a hydrostatic head and (2) dialytic batteries. Both of these approaches require the application of membranes with the accompanying life, polarization, and pumping loss problems. Other membraneless processes have been proposed and may ultimately represent the approach to achieving practical systems. As it now stands, salinity energy is a source of very large potential but it is not yet certain that its conversion to useful power can be practical. It is necessary that any ocean energy research program include fundamental understanding of those factors which limit the utilization of salinity power and the development of practical concepts which best accommodate those limitations.

Many other concepts are being proposed which would involve exploitation of the ocean energy resource. These include thermoelectric conversion of the thermal resource, use of the ocean current to drive an MHD concept, hybridization with marine geothermal, utilization of icebergs as heat sinks, and others. Each of these ideas represent a potential not presently being explored in the program because of priorities necessary due to budget realities.

Technologies survive on innovation and creativity. In the case of Ocean Energy Conversion, this innovation finds its outlet in the Alternate Ocean Systems Program. Within this program is a range of options which extends from preliminary ideas in the earliest stage of their development to well developed system concepts for which subsystem design and construction is underway. It is the intent of the program to allow the innovation and selection process to be active continuously within the framework of the schedule and budget realities of the Ocean Systems Program. The objective of providing the program with a viable and demonstrated alternative at every major decision point will be served by major open cycle OTEC experiments in the FY1985 timeframe. As events dictate, either the objective or the preferred option can change. Regular review and public scrutiny of the process will insure its integrity.

OCEAN ENGINEERING CONSIDERATIONS IN THE DESIGN OF OTEC PLANTS

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For many OTEC plant options, the most critical decisions lie within the purview of ocean engineering considerations. Early OTEC research and studies concentrated on the technology of low temperature difference heat exchangers. Ocean engineering aspects of OTEC were relegated to a position of minimum research since it was believed that the technological problems were minimal.

However such thinking does not exist today. Recent failure of the cold water pipe (CWP) attached to a test rig known as the X-1, the loss of the mini-OTEC CWP, and the OTEC-1 CWP design concerns are all examples of the state of knowledge we have today on OTEC ocean engineering.

To discuss the consideration of ocean engineering in designing OTEC plants, it is best to divide the subject into major subsystems; specifically, the platform, sea water system, cold water pipe, mooring and electric cable.

Recently platform designs have been prepared for both a grazing barge-shaped vessel and a spar platform that is anchored to the seafloor via a tension anchor leg mooring. The major concern in the design of any platform is to survive severe storm conditions. The barge and spar designs have been developed for the Pilot Plant OTEC program, namely for a 40 Megawatt (electric) (MWe) net power output. For the oceanographic conditions observed at potential Pilot Plant test sites, the platform designs already developed are marginal in regards to survivability.

For commercial platforms, such a situation does not exist because as the platform is scaled up volumetrically, all principal dimensions are also scaled, thus increasing the dimension of draft that is directly related to available freeboard which is the key dimension in any survival condition.

A recent laboratory program of the barge concept clearly demonstrated that the Pilot Plant oceanographic conditions in a severe storm can cause severe damage to the platform and could terminate the OTEC Pilot Plant program using the preliminary platform design that exists today for the barge. Thus an effort is underway to investigate measures to alleviate storm damage on the OTEC Pilot Plant platforms.

In the sea water system area very little is known regarding optimum design and potential problem areas. What we do know is that OTEC is essentially a massive sea water circulation system unprecedented in marine operations. Thus an analytical model has been developed to attempt, for the first time, to take into account the numerous parametric interdependencies the sea water loop is subject to and reacts on during normal OTEC operations.

A major component of the sea water system is the cold water pipe. The CWP has been the subject of an extensive program of design analysis and testing. Still, the problems related to the CWP are many and serious. Major problems that can only be

addressed when full scale CWP's are developed (30 foot diameter for the Pilot Plant) include construction techniques, transportation schemes, deployment operations, platform/CWP interface hardware capabilities, normal and survival operations.

Currents loads, wave loads and platform loads all produce large CWP stresses. Trends today for suspended CWP's (those attached to a floating platform) are towards light-weight, thin-walled, flexible structures built out of fiberglass or rubber to mitigate stresses and interface loads. Bottom-siting CWP designs still include pipes constructed out of standard marine materials of steel and concrete. It is predicted that the highest technical risk item on any ocean-going OTEC plant will be the CWP. The same is true even for OTEC designs intended for shallow water areas, where both intake and discharge pipes for both warm and cold water pose serious designs problems for ocean engineers.

A one-third scale at-sea experiment will begin early in 1981 of a fiberglass CWP, 10 foot in diameter, 1000 feet in length. The pipe will operate in up to 9 foot seas to simulate hurricane conditions of a full scale 30 foot diameter, 3000 foot long CWP for the Pilot Plant program.

Mooring system activites have mainly addressed the requirements for the OTEC Pilot Plant. Findings to date have indicated that standard design practice can be followed for many OTEC plant designs. However, several potential OTEC sites with unknown soil conditions do not provide sufficient data to design appropriate anchor systems. Projects are beginning that will obtain such design data.

The electric cable poses a serious problem interfacing between mooring lines and the various sea water intake and discharge pipes. The major difficulty is potential damage to the electric cable from plant/subsystem excursions. Until a specific plant design is underway, it is difficult to assess the potential damage in the cable.

In conclusion, the concerns and considerations of the ocean engineering designers for OTEC plants are mainly restricted to platform survivability and CWP stress reduction. Other ocean engineering subsystems are within the standard marine practice and are not viewed as important problem areas. The major considerations of full scale construction, installation and deployment can only be resolved when the Pilot Plant is operational.

ENVIRONMENTAL ASSESSMENT AND MONITORING FOR OCEAN THERMAL ENERGY CONVERSION (OTEC)

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The four major classes of environmental concerns and the key issues in these classes associated with OTEC deployment are:

Redistribution of Oceanic Properties	Structural Effects
ocean water mixing	artificial reef
impingement/entrainment	nesting/migration
climatic/thermal	
Chemical Pollution	Socio-Legal-Economic
biocides	worker safety
working fluid leaks	enviro-maritime law
corrosion	secondary economic impacts

The potential changes in the oceanographic properties of sea water due to OTEC pumping operations are a major environmental concern. Because large amounts of cold, deep water and warm shallow water will be pumped to the heat exchangers, likely at some third depth; parameters such as temperature, salinity, density, dissolved oxygen, nutrients, carbonates, particulates, etc., will be modified by mxing with ambient ocean water in the vicinity of the eventual discharge. Discharges in the photic zone may cause biostimulation due to the increased nutrient contribution from the deep waters, with potential changes in either the size, relative abundance or species composition with respect to the resident marine population resulting in secondary effects on the food web. Displacement of sea water also could have toxic effects on ambient species by the introduction of trace chemical substances such as trace metals, organic decay products, etc., from other depths. Certain species, particularly those with low mobility, will be harmed by impingement/entrainment in the pumping system either by contact with the screens and walls of the pipe-heat exchanger system or by the pressure and temperature changes encountered in transit of the system from intake to discharge.

Chemical pollution could result as functions of various OTEC plant operations and maintenance procedures. Of major concern are biocides proposed to keep the system components clean of biological growth. There are alternative ways (various mechanical systems) to clean heat exchanger systems, but these may not clean surfaces to the extent necessary for efficient operation. The major problem with biocides is the levels of concentration needed to impede biological growth in the system which unquestionably will affect organisms in the vicinity of the discharge. Furthermore, if chlorine is used as a biocide and ammonia as a working fluid, accidental combinations of these chemicals can produce compounds even more toxic to ambient organisms than the separate chemicals. Leaks of the working fluid of a closed cycle system also will

pollute ambient ocean water. The effects and chemical fate of proposed working fluid leaks into sea water are not well understood. Ammonia, for example, is a nutrient in proper amounts and could stimulate marine growth complicating the biofouling problem. However, the excessive doses associated with a major leak is toxic both to marine and human life. Chemical pollution also will be produced by the corrosive effect of sea water passing through the heat exchanger system. Corrosion would produce metallic ions, and scale particles which could have direct toxic effects or long-term effects through incorporation of corrosion products into the particulate food supply of marine organisms through the process of bioaccumulation.

The physical presence in the ocean of a structure the size of an OTEC system itself has an impact on the ocean. The structure of whatever configuration will become an attractive habitat for a wide range of organisms based on experience from artificial reefs. The long-term effects of the structure on the environment will depend on the types, size, and abundance of the organisms attracted to or attached to the structure and this will modify the local population. Regional effects on populations might occur by either interference with, or modification of, nesting habits or migration pathways.

The first three major classes of concerns chiefly dealt with impacts on marine life. However, there are human consequences of OTEC operations which are grouped here as socio-legal-economic issues. Worker safety is of prime concern regulated by the Occupational Health and Safety Administration (OSHA) and the Coast Guard for strictly marine occupational concerns. Potential work hazards are the chemicals used or produced by the OTEC system such as ammonia, chlorine, foul weather during marine operations, collision, and systems accidents. Because of the novelty of OTEC operations, standard safety procedures will be augmented by procedures unique to OTEC. The siting of OTEC facilities either in international waters or where the downstream effects of OTEC operations might intrude into international waters, will raise the issues of international rights and responsibilities beyond those treated by conventional maritime law and treaties.

In general, mitigating strategies can be used to alleviate many deleterious environmental effects of operational problems as biostimulation, outgassing, etc. Various research studies on toxicity, biocide releases, etc., are under way or are planned to investigate areas where no clear mitigating strategy is available. A Master Plan listing procedures to be followed to identify and evaluate potential concerns at any OTEC proposed site is proposed for discussion and refinement in advance of any real OTEC test operations.

Ecologically sound operations of projected Ocean Thermal Energy Conversion (OTEC) plants can be insured by careful attention to the marine environment during the design phase. This requires quality information from regions of potential OTEC interest. Currently, preliminary or actual surveys and laboratory studies are being conducted in the waters of Puerto Rico, the Gulf of Mexico, Hawaii, and Guam for potential moored OTEC plants and in the equatorial South Atlantic for proposed plant-ship operations to provide such benchmark and baseline data. These data plus existing archival information can be used to model effects of OTEC operations based on projected design schemes.

As the OTEC program enters the hardware phase with the deployment of the one megawatt equivalent test platform (OTEC-1) in 1980, the environmental data required for permitting and eventual design for commercialization is becoming more extensive and more sophisticated. The programmatic environmental assessment was issued in early 1980 and the generic environmental assessment for the next test platform (OTEC 10/40) will be completed by the summer of 1980 to be available prior to contract award. One year's monitoring at benchmark sites in the Gulf of Mexico (Tampa and Mobile); Puerto Rico (Punta Tuna); Hawaii (Kona Coast/OTEC-1); and at the grazing ship site (Equatorial South Atlantic) have been completed. Archival studies have begun for Guam and a new benchmark site (southwest Oahu) is being occupied starting in early 1980. Data from these sites will be analyzed to be available to aid in site selection for future test deployments.

LEGAL AND INSTITUTIONAL ASPECTS OF OTEC DEVELOPMENT

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An extensive effort to resolve many of the legal, institutional and financial barriers to the development of ocean thermal energy conversion ("OTEC") resulted this year in the enactment of several significant laws.

On April 2, 1980, the President signed Public Law 96-223, the Crude Oil Windfall Profit Tax Act. The first step in resolving OTEC's financing questions, that legislation added to the 10 percent investment tax credit generally available an additional 15 percent credit for OTEC equipment at two sites yet to be selected. This 15 percent credit is available through 1985.

On July 18, 1980, Public Law 96-310 was signed. Entitled the Ocean Thermal Energy Conversion Research, Development, and Demonstration Act ("Demonstration Act"), the law directs the Department of Energy to accelerate its OTEC program, to develop by 1986 two OTEC demonstration facilities with a combined capacity of 100 megawatts, and establishes a longterm national goal to achieve by 1999 10,000 megawatts from OTEC systems.

On August 4, 1980, the President put the finishing touches on the 1980 OTEC legislative program by signing Public Law 96-320, the Ocean Thermal Energy Conversion Act of 1980 ("OTEC Act of 1980"). That bill provides OTEC legal certainty by establishing a licensing and permitting program within the National Oceanic and Atmospheric Administration and authorizes use of the Maritime Administration's Loan Guarantee and Capital Construction Fund programs. In addition, it makes construction and operating differential subsidies available for OTEC support vessels.

These are impressive results indeed for the efforts of the OTEC community. But they are not enough. Seeing OTEC through to commercialization will require removal of other legal, institutional and financial barriers.

First, it will be necessary to monitor the Department of Energy's progress in carrying out the short term and long term goals of the Demonstration Act. A critical factor will be the conversion of national OTEC goals into full-scale appropriations, a difficult task in these times of economic stress.

Second, careful attention should be given the issue of cost sharing for the OTEC pilot plants. The Federal share of such plants will be subject to multi-year appropriations.

Third, the new licensing regime established by the OTEC Act of 1980 will require fine tuning. The content of NOAA regulations implementing the regime will be almost as important as the Act itself. Moreover, there will be many issues arising from the new law of the sea treaty which now appears on its way to adoption by the U.N. Law of the Sea Conference.

Fourth, the role of provisions of the OTEC Act of 1980 extending Maritime Administration financing to OTEC will raise a number of important questions. Among them is whether the pilot plants mandated by the Demonstration Act will qualify for loan guarantees.

Fifth, the participants in the OTEC industry will want to analyze their tax posture thoroughly. Structuring its plans to derive maximum advantage from the available tax benefits should be high on the corporate agenda.

Sixth, there undoubtedly will be a need for additional legislation as the industry's needs and bottlenecks become more apparent. Examples of possible action are extending the energy investment tax credit beyond 1985 and providing producer incentives for OTEC materials such as titanium.

Obviously much remains to be done. Yet OTEC is measurably closer to commercialization now than it was a year ago, and it will move even closer still with a concentrated, cooperative effort of the OTEC community.

AT SEA WITH OTEC LEGISLATION: A CONGRESSIONAL VIEW

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The creation of the Energy Research and Development Administration in January, 1975, brought an embryonic solar energy program out of the shadows in which it had sprouted in the National Science Foundation. Starting in 1974 the Congress has, each year, taken major legislative initiatives to promote solar energy technologies either collectively or individually. From a Federal budget of about $1 million in FY 1972, the Federal budget now contemplates expenditures of about $1.5 billion in FY 1981 for solar research and development, procurement, and incentives. To date the funding growth in most technologies has been at a rate sufficient to strain the ability of the solar community to meet the opportunity. Until the 96th Congress, OTEC was one clear solar technology which did not receive significant Congressional attention.

The first efforts to edify Congressional Members and staff regarding OTEC started during consideration of the first ERDA authorization in 1975. Unfortunately some OTEC advocates only succeeded in poisoning the well due to their approach. Until 1977 funding for OTEC was largely overlooked by the Members of the committees of jurisdiction. The annual OTEC funding was largely determined by the request submitted by the Administration.

About three years ago the awareness of a few Members of the Congress was heightened regarding the prospects for achieving economically viable OTEC systems. Hearings by the Senate Committee on Energy and Natural Resources were held in Hawaii in late 1978 on the topic of achieving energy self-sufficiency through the use of renewable energy resources. As a result of those hearings, Senator Matsunaga (D-Hawaii), a Member of the Energy Committee, became totally committed to this concept and saw OTEC as an integral part of the Hawaiian energy self-sufficiency plan.

At the request of Senator Matsunaga, the staff of the Subcommittee on Energy Research and Development undertook in July, 1979 a detailed critical review of the status of OTEC technology and of the DOE program. Completion of that review resulted in a finding that there was a clear opportunity and need for accelerating the DOE OTEC program. A bill was then drafted at the request of Senator Matsunaga and he introduced S. 1830 on September 27, 1979. The bill's aim was to complete the research and development phase and to initiate the demonstration phase in the DOE OTEC program. A companion bill was introduced in the House by Congressman Fuqua (D-Fla.) shortly thereafter. The legislation became law in July, 1980 after full consideration by each House. The basic thrust of this legislation is to establish aggressive national goals and to achieve early demonstration of the technology by authorizing twice the amount of the Administration's budget request of $40 million for FY 1981 and setting a FY 1982 authorization of $85 million.

This law establishes an aggressive national OTEC program which will lead naturally to the commercialization phase which will hopefully be initiated in the mid-to late -1980's. However, entering this phase will not have to await additional legislative action because both investment tax credits and loan guarantees to promote commercialization of OTEC have been enacted into law by the 96th Congress. The "windfall profits" oil taxation legislation contained tax credits for the first few OTEC facilities. This provision was included at the instigation of Senator Matsunaga.

Broad generic regulatory and financial incentive legislation was introduced by Congressman Studds (D-Mass.) and by Senator Inouye (D-Hawaii) during the 96th Congress. The regulatory provisions require the Administrator of NOAA to make a number of negative determinations in order to prevent the licensing of a commercial OTEC facility. The Secretary of Commerce is authorized to use up to $2 billion in loan guarantees under an expanded MARAD program to provide a financial incentive for commercial OTEC facilities. The legislation was modified with floor amendments in the Senate to make it fully complementary with the Matsunaga bill. The Studds-Inouye bill became law on August 4, 1980.

Through the efforts of several key Members of the 96th Congress, OTEC has now moved into a highly visible position. With the continued Congressional support for the DOE program, it is the responsibility of the OTEC community to make the most of the present opportunity and to achieve the commercial use of OTEC.

missing

STATE AND LOCAL SUPPORT FOR OTEC: CLEARING THE PATH

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State and local support for OTEC begins when a community decides that OTEC provides an opportunity with major potential benefits. The next step is to both evaluate and attract that opportunity, in order to shape development toward that configuration which is of greatest benefit to the community. The community's preferred path to OTEC power will emerge as State and local organizations interact with industry, promote research, facilitate commercialization, assess impacts at specific sites, and keep the general public informed of all developments.

Hawaii has decided that OTEC provides an opportunity with major potential benefits. The development of ocean energy is encouraged by the Hawaii State Plan and the State Energy Plan. The timetable and scale of OTEC development which will be most beneficial to the State is being explored in the context of other alternate energy sources in the Hawaii Integrated Energy Assessment.

The State Department of Planning and Economic Development (DPED) has drafted a working document, "The State of Hawaii OTEC Program 1980-1985," to map out the planned activities of various public institutions interested in developing Hawaii's OTEC potential. That working document describes the following areas of activity necessary to both evaluate and attract an OTEC industry:

1. Industry interaction. State and local government officials, businessmen, and academicians need to interact with OTEC industry representatives and federal program officials to learn about their plans, and explain to them the resources and capabilities of the local community. The information thus obtained allows the State and local community to plan its activities in conjunction with industry and federal programs.

2. Research promotion. Industry/federal government interaction can identify research projects which can be conducted in the community to advance the development of OTEC technology. This research allows local scientists and engineers to develop expertise in OTEC operations, thereby building an academic capability in the community which can support commercial OTEC operations. In 1974, the Hawaii State Legislature established the Natural Energy Laboratory of Hawaii (NELH) and set aside a 320-acre shorefront site at Ke-ahole Point on the Island of Hawaii for a research facility. At the same time, the Legislature established the Hawaii Natural Energy Institute (HNEI) to conduct energy research. In 1978, State and County of Hawaii officials formed a development group which won U.S. Department of Energy (DOE) and State funds to establish the Seacoast Test Facility (STF) at NELH. NELH, HNEI, and STF now form the core of the OTEC research carried on in Hawaii. These institutions have made Hawaii a world center for OTEC research.

3. The facilitation of commercialization. Commercialization can be facilitated by State and local communities through appropriate planning, infrastructure studies, the streamlining of permit procedures, financial support, community support, and demonstration

projects. In Hawaii, the State participated in Mini-OTEC, the world's first at-sea closed cycle OTEC plant to produce net energy. State government agencies are now participating with industry consortia bidding for the DOE's OTEC pilot plant. The State Legislature has passed a resolution indicating its commitment to provide financial support to the pilot plant project.

State and local communities can also offer tax advantages, loan government land or facilities, and study the infrastructure requirements of the new industry to identify needs and meet those needs with major capital improvements. Different sectors of the community can identify impediments to commercialization and work to improve laws and regulations, educate the public, and fashion the proper relationships for capital formation, ownership, and operation of OTEC plants. A major risk factor in the establishment of an OTEC plant is the permit process. The speed of the process depends upon the number of permits required, the number of agencies involved, what information is needed, and the level of understanding of the decision-makers. In 1977, the Hawaii State Legislature passed Act 74 to coordinate permit procedures and centralize permit information. In 1978, the DPED's Coastal Zone Management Program began a study of permit procedures for the purpose of making recommendatons to streamline the system.

4. Impact assessment. Before an OTEC plant is built, the people of the State and local community will need to estimate the environmental, social, and economic impacts in order to maximize the benefits and minimize the costs.

Environmental studies are necessary both for site selection and permit procedures. Site selection depends partly upon the environment at each potential site, what the negative impacts will be, and to what extent they can be mitigated. In this regard, the Ad Hoc Committee for the Advancement of OTEC in Hawaii has produced a report entitled OTEC FOR OAHU, which describes the environmental and design studies necessary to establish an OTEC pilot plant off Kahe Point, Oahu. The Hawaii State Legislature has appropriated funds to carry out the recommended studies.

The siting of an OTEC plant also depends upon social and economic impacts. Throughout all OTEC development activities, it is important to identify and respond to the concerns of the local community. These concerns may involve the physical appearance of the plant; its impact on marine life and fishing in the area; its impact on the shoreside community, including the building of new facilities; and job prospects, including the problem of the importation of labor during construction. The long-term success of OTEC is affected by the OTEC plant's relations with its neighbors. In Hawaii, socio-economic impact studies are planned in regard to the proposed Kahe pilot plant site.

5. Public information. All of the above activities are easier if the general public knows about OTEC and takes an interest in the opportunities it provides. A community which knows about OTEC can share in guiding its development, and can take pride in its becoming a reality. Publications, briefings, workshops, lectures, and seminars should be held for government officials, businesses, community groups, students, and media representatives. In Hawaii, DPED, the State Marine Affairs Coordinator, and the University of Hawaii Sea Grant Program provide these public education services regarding OTEC.

There is yet time for State and local communities to identify their preferred path for OTEC development, and clear that path so that sites will be ready when the technology is scaled up. There is still time to influence OTEC plant design, location, and operation so that commercial scale plants will fit in with the plans and desires of State and local communities, becoming an environmentally sound, socially acceptable, and economically beneficial contributor to State and local energy needs.

ANL FACILITY FOR THE PERFORMANCE EVALUATION OF OTEC HEAT EXCHANGERS

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In December, 1976 ANL (Argonne National Laboratory) submitted a proposal to ERDA (Energy Research and Development Administration) for an integrated experimental and analytical program to evaluate the thermohydraulic performance of heat exchangers under simulated OTEC flow and temperature conditions. It was proposed to utilize the results of the single tube tests obtained earlier at the Oak Ridge National Laboratory, Union Carbide Linde, and Geoscience, Inc. and subsequently generate heat exchanger data and design methods by which it would be possible to scale to power plant size modules. The proposal offered attractive cost savings to ERDA due to the availability of a fully equipped building. The building, part of the deactivated high energy particle accelerator complex, had steam, electrical power, cooling tower capacity, high loading concrete floor and a 20-ton crane with a 23 foot hook height.

The A-E work was initiated by Lester B. Knight Associates, Inc. later taken over and completed by Globe Engineering Co. The construction started in March, 1977 and was completed in November, 1977. No significant cost overrun over the initial estimate of $800K was incurred.

A decision was made to construct the facility with two completely independent closed fresh water loops: one cooled by a freon chiller of 500-ton capacity and the other heated by steam. In the third loop, ammonia vapor flows from the evaporator through an expansion valve into the condenser and the liquid is returned to the evaporator by a feed pump. The operating conditions of the facility are highlighted in Table 1. The original design provided for a rapid test unit changeover capability. This feature allowed us to save time with the original test articles and reduced installation effort with later units.

The data acquisition system is computer based. Temperature, flow and pressure transducer signals are conditioned by appropriate interface modules which are periodically interrogated by a Data General Nova 3 computer programmed to calculate and display selected data on a CRT, to print out a hard copy, and to provide tape storage. The instrumentation listed in Table 2 is used in the determination of the two quantities used to characterize the performance: the overall heat transfer coefficient U and the pressure drop.

Table 1 Test Facility Operating Conditions

Parameter	Nominal Value	Range
Heat Duty of Test Units, Btu/hr	3.2 million	2.4 million-4.6 million
Warm Water Supply Temperature, °F	80	75-85
Cold Water Supply Temperature, °F	40	40-45
Water Temperature Change, °F	2	2-4
Log-Mean Temperature Difference, °F	7	4-10
Water Flow Rate, gpm	3200	1500-5000

Table 2 Instruments and Measurement Accuracy

Quantity Measured	Instrument	Accuracy of Measurement
Temperature of:		
Water into and out of heat exchanger Ammonia vapor in evaporator and after expansion valve	Quartz crystal thermometer	±0.020°F
Pressure of:		
Ammonia vapor in heat exchanger and after expansion valve Ammonia feed pressure to evaporator	Quartz crystal transducer	±0.005 psi
Pressure Difference of:		
Water into and out of heat exchanger Water into and out of pump Static head of liquid ammonia in evaporator (liquid level)	Strain gauge transducer	±0.5% of reading
Flow Rate of:		
Water through heat exchanger	Turbine Meter	±0.15% of reading
Liquid ammonia feed to evaporator	Turbine Meter	±0.5% of reading

A pool boiler with titanium tubes clad with Union Carbide Linde High Flux enhancement on the ammonia side was tested first. A significant effect of High Flux surface deactivation by prolonged contact with liquid was uncovered in this test. The effect has since been reproduced several times and a procedure developed for avoiding it completely or drastically reducing the recovery time. Since the initial tests, four evaporators and four condensers including shell and tube, shell-less, and compact designs have been successfully tested.

The ANL facility in its three years of operation has generated essential information. The data is available for more accurate performance analysis of the pilot plant as well as for planning and checking results obtained on tests to be done on OTEC-1 and the seacoast test facility. The ANL facility will continue to play an important role in the OTEC program. Precision data can be obtained quickly, reliably and economically without complication of corrosion or fouling. Present plans call for a full program in FY 1981 in support of OTEC-1 second deployment.

All the engineering is completed for an expansion of up to 14,000 gpm water flow rate and 20 million Btu/hr heat duty. The modification could be accomplished in a 9-12 month time span. The engineering was done with a view of testing larger OTEC heat exchangers or open cycle turbines; however, obviously the facility can be utilized for bottoming cycle tests or other tests requiring low temperature differences.

OTEC RESEARCH ASHORE
THE ROLE OF THE SEACOAST TEST FACILITY

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The idea of generating power using the temperature differences between the deep cold and warm surface water of the tropical oceans of the world was first propounded by d'Arsonval as far back as 1881, followed by the American engineer Campbell, the Italians Dornig and Boggia, and the German physicist Brauer. Serious attempts to demonstrate this concept on a large scale began in 1929 with the efforts of Georges Claude to build a shore based plant in Cuba to produce electrical power. While technically of interest his efforts did not result in a system capable of generating net positive power due to limitations in the supporting technologies, especially materials and pipeline construction, as they existed at that time. With the continued development of cheap energy systems based on oil, interest in developing this ocean thermal energy conversion (OTEC) technology waned.

The OTEC concept was not seriously revived within the United States until the problems of the U S dependence on imported oil became a national concern. As the planning commenced for OTEC technology development a need was identified for a capability to test and qualify various materials, components and subsystems that go into making a successful OTEC system. To provide this capability in a cost effective manner a facility, or set of facilities, is required. Basic facility capabilities to support the necessary research were identified, and included: a) adequate and easily expandable space, b) reliable logistics support, c) reliability of long term operations, d) realistic test conditions, and e) low cost per unit of information obtained. Two basic approaches are possible, an offshore floating platform or a shore-based facility. Offshore platforms have advantages only in the area of providing more realistic test conditions than are possible with most shore sites, and are in fact most appropriate for large scale systems integration experiments such as a pilot or prototype plants. On the other hand a properly sited onshore facility has advantages in all the capability areas for testing and experimentation up through the major component and subsystem testing level. Specifically, properly located shore facilities are easily expanded to provide additional space; logistics support is easily provided via regularly scheduled commercial transportation systems; facilities operating costs are much lower ashore for any given level of support; long-term reliability of experimental operation greatly exceeds that of all but the largest ocean based platforms; and with proper siting the seawater supply can be essentially the same as an operating OTEC plant would see.

The Seacoast Test Facility, (STF) which is part of the Natural Energy Laboratory of Hawaii (NELH) located at Ke-ahole Point on the island of Hawaii, is just such a shore based OTEC research facility. The STF is being developed as a cooperative venture between the State of Hawaii and the United States Department of Energy (DOE). Construction is being implemented in two stages, with the first including the basic laboratory and support facilities and

utilizing an existing state-owned warm seawater supply. The second stage, now programmed for construction in federal fiscal year 1982, will provide the major warm and cold seawater supply, distribution and disposal system.

The research program planned for the STF has begun with a series of experiments in support of the Biofouling Countermeasures portion of the DOE OTEC Biofouling, Corrosion and Materials (BCM) Program. Specifically, a series of eighteen single tube Heat Transfer Monitors are being installed along with their related biofouling and corrosion sample sections to qualify one or more cleaning systems. Cleaning system qualification requires two years of continuous operation while maintaining the resistance to heat transfer (R_f) within defined bounds. Near term expansion calls for additional experiments involving compact (plate type) heat exchangers and additional types of cleaning systems. Concurrent experiments will be investigating the biology of the biofouling organisms and the corrosion of selected candidate materials for OTEC system applications. As the OTEC heat exchanger designs are more fully developed long term testing of selected modules in sizes up to 1 MW_t are planned.

With the inclusion of a mariculture component in the federal OTEC research effort, as mandated by Senator Matsunaga's OTEC legislation, plans are being developed for a mariculture research facility that would supplement the work being done by the BCM Program. Work at this facility, which would be physically interconnected with the Seacoast Test Facility, would focus on those projects that offer the promise of utilizing the nutrient and temperature resources of the discharge waters from a commercial size OTEC plant. Potential mariculture systems that may be applicable range from an algae which can be processed to provide hydrocarbon oils to salmon which provide a high quality protein for human consumption.

MINI-OTEC - AN OPERATIONAL OTEC PLANT

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Introduction: The potential of Ocean Thermal Energy Conversion (OTEC) as an alternate energy source was established in the early 1970's through a National Science Foundation feasibility study. Subsequent government funded studies have reaffirmed this finding and the desirability of a physical demonstration of the OTEC concept.

The concept of a modern, small-scale, at-sea demonstration of a closed-cycle OTEC plant was proposed by the University of Hawaii and Lockheed Missiles & Space Co. late in 1977. The eventual result of this proposal was the design, construction, deployment, and operation of Mini-OTEC off the Kona Coast of the Island of Hawaii.

Mini-OTEC was developed under a cooperative research agreement between the State of Hawaii, Dillingham Corp. and Lockheed Missiles & Space Co. with participation by Alfa-Laval, Inc., who loaned the plate heat exchangers to the program and assisted Lockheed in the plant design, and Worthington Pump Corp. who provided the seawater pumps at no charge to the program. The program was broken down into two broad areas of responsibility; the State of Hawaii, with project management by Dillingham Corp., was responsible for providing the mooring system, the cold and warm water to the heat exchangers, modification to the surplus Navy barge and all marine operations; Lockheed Missiles & Space Co. was responsible for System Integration and for the design, fabrication, and operation of the power plant. Makai Ocean Engineering performed the engineering services for the State, and Offshore Hawaii performed the marine and operational services to the platform after deployment.

Power Plant Design: A Rankine cycle (closed-cycle) power plant was used on Mini-OTEC with ammonia as the working fluid. The plant was designed to produce 50 KW gross power with a net generated power in the range of 10-15 KW. The design seawater temperature difference was 37°F based on cold and warm seawater temperatures of 43 and 80°F. As a result of cost and time limitations, the major components, i.e., the turbine-generator, heat exchangers, and ammonia and seawater pumps, were off-the-shelf items.

The turbine was a single-stage, radial-inflow turbo-expander manufactured by Rotoflow Corp. The turbine ran at 28,200 rpm driving a 3,600 rpm 3-phase generator through a reduction gear. The output was approximately 50 KW at a power factor of 0.8 with 120/208 volts at 60 HZ.

Mini-OTEC had plate-type heat exchangers for the evaporator, condenser, and preheater manufactured by Alfa-Laval of Lund, Sweden. Both the evaporator and condenser contained 260 titanium AX-30 plates, which resulted in individual heat transfer areas of 4,390 ft^2. The ammonia vapor rate for both the evaporator and condenser was on the order of 5 lbm/sec with evaporator liquid flow rates as high as 10 lbm/sec. Biofouling control was maintained by continuous chlorination at approximately 0.1 ppm. The preheater was used to provide liquid ammonia to the evaporator at the saturation temperature.

The cold and warm seawater pumps provided by Worthington were the 12KLD, 1760 rpm wet-pit type with axial flow impellers. The nominal flow rate was 2,700 gpm with a cold water pump head of 18 ft. and a warm water pump head of 14 ft.

The ammonia pumping requirements were accommodated by variable speed positive displacement pumps. Parajust speed controllers were used to maintain the separator sump liquid level and the preheater/evaporator liquid ammonia flow rate.

MINI-OTEC OPERATING CONDITIONS

	Turbine Inlet	Turbine Outlet	Reser-voir	Evap. Inlet	Evap. Outlet
Pressure (PSIA)	130.0	92.0	92.5	132.3	130.1
Temperature (°F.)	70.5	51.6	48	70.6	70.7
Ammonia Flow Rate (Lbm/Sec)	5.1			7.3	7.3
Quality (%)	99.9	97	0	0	70

Cold Water Flow)
- 2,700 GPM Each
Warm Water Flow)

Cold Water Pipe/Mooring System: Mini-OTEC employed an integrated Cold Water Pipe (CWP)/Mooring System. In this arrangement, the CWP also functions as a tension member in the single point mooring system successfully employed on Mini-OTEC. The CWP was fabricated from 40 ft. sections of 2 ft. diameter high density polyethylene pipe with a total length of 2,150 ft. Since high density polyethylene has a specific gravity of 0.95, the bottom of the CWP required a 5,000 lbm lead ballast to counteract its buoyant force. The connection to the barge from the top of the pipe was made with a specially fabricated 18 inch diameter rubber/wire suction hose. The bottom of the mooring was held in place by a 30,000 pound (wet wt.) concrete clump anchor, which was prevented from sliding down the slope by a wire rope connected to an inshore drag anchor. The necessary scope was provided by 1,500 ft. of buoyant polypropylene line between the clump anchor and the bottom of the cold water pipe.

Results: The primary result achieved by Mini-OTEC was the successful demonstration of OTEC technical feasibility. Mini-OTEC represented the first demonstration of net OTEC power, the first at-sea operation of an OTEC plant, and the first operation of a closed-cycle OTEC plant. The elapsed time between the beginning of fabrication and the first successful operation of the plant on 2 August 1979 was nine months. In addition to demonstrating technical feasibility, Mini-OTEC provided a significant amount of OTEC operating experience along with general verification of the power plant engineering design. Mini-OTEC represents a significant contribution to the eventual commercial application of ocean thermal energy.

SECTION 8

GEOTHERMAL

GEOTHERMAL

Program Chairman: *Stanley H. Ward,* University of Utah Research Institute
DOE Advisor: *John Salisbury*
Overview Presentation: Wednesday, December 10, 4:00 P.M.

"Overview of Geothermal Hydrothermal Development" 2-84
Bennie G. DiBona and Ronald S. H. Toms, DOE

SESSION I: Tuesday A.M.
Geosciences

"Petrologic Indicators of Fluid Flow in High Temperature Geothermal Systems" 8-1
W. A. Elders, Institute of Geophysics and Planetary Physics
"Geology of Low- and Intermediate-Temperature Hydrothermal Systems" 8-3
Dennis L. Nielson, University of Utah Research Institute
"Fluid Geochemistry and Geothermometry" 8-5
Alfred H. Truesdell, U.S. Geological Survey
"Geochemistry of Solids in Geothermal Systems" 8-7
Joseph N. Moore, University of Utah Research Institute
"Geothermal Geophysics" 8-9
Phillip M. Wright, University of Utah Research Institute

SESSION II: Tuesday P.M.
Reservoir Engineering, Drilling, Stimulation

"Geothermal Exploration" 8-11
Gary W. Crosby, Phillips Petroleum Company
"Geothermal Well Logging – The State-of-the-Art" 8-13
Subir K. Sanyal, Stanford University Petroleum Research Institute
"High Temperature Geothermal Reservoir Engineering" 8-15
J. H. Howard, Lawrence Berkeley Laboratory
"Testing and Analysis of Low-Temperature Hydrothermal Reservoirs" 8-17
D. Goldman and S. Petty, EG&G Idaho, Inc.
"Interference Testing in Geothermal Reservoirs" 8-19
Henry J. Ramey, Jr., Stanford University
"Geothermal Well Stimulation Treatments" 8-22
R. J. Hanold, Los Alamos Scientific Laboratory
"Geothermal Utilization Technology" 8-24
T. E. Walsh, J. W. Hankin, and G. F. Cochrane, Bechtel National, Inc.

SESSION III: Wednesday A.M.
Utilization Aspects

"Recent Federal Geothermal Legislation" 8-26
John T. Nimmons, Earl Warren Legal Institute
"Geothermal Market Development and Commercialization Programs in the Western States" 8-28
Richard T. Meyer, Barbara A. Coe and W. Darrell Gertsch, Western Energy Planners, Ltd.
"Direct Application Overview" 8-30
John W. Lund, Oregon Institute of Technology
"The Use of Geothermal Energy for Biomassed-Based Ethanol Fuel Production" 8-32
Clayton R. Nichols, DOE/Idaho Falls, and *Debra W. Struhsacker,* University of Utah Research Institute

***Abstract not available for printing in Conference Proceedings**

Session III (continued)

"Geothermal Electrical Production in the U.S., Problems and Future Perspectives" 8-34
David W. McClain, Morrison-Knudsen Company, Inc.
"Environmental Issues & Concerns in Development" 8-36
Susan G. Spencer, EG&G Idaho, Inc.
"Geothermal Financing Opportunities and Accomplishments" 8-38
Paul Rodzianko, Geothermal Energy Corporation

SESSION IV: Wednesday P.M.
Summary Session

"Hawaiian Geothermal Resource Assessment and Application" 8-40
Charles Helsley and Donald Thomas, Hawaii Institute of Geophysics
"3 MWe Wellhead Generator Project" 8-43
J. T. Kuwada, Geothermal Kinetics, Inc., and *R. J. Farrington,* Rogers Engineering Co., Inc.
"Summary of Well Test and Reservoir Engineering Results for HGP-A" 8-45
Paul Yuen, Bill Chen, Deane Kihara, and Art Seki, Hawaii Natural Energy Institute
"Union's Philippines Projects" ..... *
Carel Otte, Union Oil
"U.S. Direct Use Demonstration Projects" 8-48
Edward G. DiBello, EG&G Idaho, Inc.

PETROLOGIC INDICATORS OF FLUID FLOW IN HIGH TEMPERATURE GEOTHERMAL SYSTEMS

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Hydrothermal minerals are the tangible records of the flow of hot fluids through rocks. Reactions between fluids and rocks at elevated temperatures cause changes in the physical properties of both at rates which are extremely rapid compared to most geological processes. Boiling, the encounter of hot water with cold rock, and the encounter of cold water with hot rock all have dramatic effects on the solution and precipitation of minerals. Hence permeability varies in space and time during the lifetime of a geothermal system.

Precipitation of minerals reduces porosity and seals fractures, reducing permeability. Solution of minerals at moderate depths and temperatures has the opposite effect. At higher temperatures and greater depths incongruent solution forms denser minerals, solution tends to occur at grain to grain contacts and pore space collapses under the lithostatic load. Thus intense fluid-rock reaction is self-limiting as flow paths tend to close off. In many mature geothermal systems fluid flow is maintained only by faulting and hydraulic fracturing, and these fractures are repeatedly sealed by mineralization and reopened by renewed fracturing.

In our work on the high temperature systems of the Salton Trough, we have used these tangible records to chart the fluid flow regime in geothermal reservoirs in the undisturbed state, before production. In addition to examining the textures and fractures of the reservoir rocks, our approach uses diagnostic patterns of alteration minerals, of isotopic exchange between minerals and fluids, and various kinds of geothermometry and dating. Although fluid geothermometers are useful in this kind of study, they give average values over large volumes of the reservoir. Mineral geothermometers record a temperature which is specific to a certain point in space and time. These geothermometers include temperature dependent mineral assemblages, isotope ratios in minerals, vitrinite reflectance in minute plant fragments, and fluid inclusions. Use of several different thermometers simultaneously provides the best insight into the thermal history of a given subsurface sample. This is because different geothermometers have different time constants and so have different memories of fluid-rock reaction. Mineral assemblages and isotopic exchange depend both on temperature and upon water to rock ratio. Several of our studies have shown that both minerals reactions and isotopic exchanges occur at lower temperatures in sandstones than in shales. This is because the lower permeability of shales has allowed only limited flow compared to that in the more permeable sandstones. In general, mineral assemblages and vitrinite reflectances behave like maximum thermometers, they do not retrograde when temperatures fall. On the other hand, isotope ratios more readily adjust to temperature change in either direction, provided that fluid flow is adequate to permit reaction to occur. Fluid inclusions, however, record the conditions of temperature and salinity at the time of crystal growth. The temperatures recorded by any of these geothermometers may, and often do, differ from those measured directly by borehole temperature logs. Frequently this is because a well is not in thermal equilibrium with the formation. When equilibrium temperature logs are available, the comparisons between the temperature methods allows us to infer the temperature history. The most direct method of determining the duration and age of

heating is one which records the thermal events themselves. We are currently dating the thermal events of the Salton Trough using fission track annealing. For example, the well #366 (Fig. 1) in the Cerro Prieto field of Baja California, Mexico reached a temperature of 150°C less than 10,000 years ago according to fission track studies.

The purpose of these studies is to gain insight to hydrothermal hydrology. At present our best studied example is the Cerro Prieto geothermal field. We have used this approach to determine (a) the shape and size of the reservoir; (b) the nature of its boundaries; (c) the temperature distribution within it and the direction of temperature change; (d) the ratios of water to rock and the degree of openess of the system; (e) the location of zones of heating, of discharge of hot water, of plumes of boiling water, and of zones of recharge of cold water to replenish the system. Figure 1 is an example which shows the application of this approach.

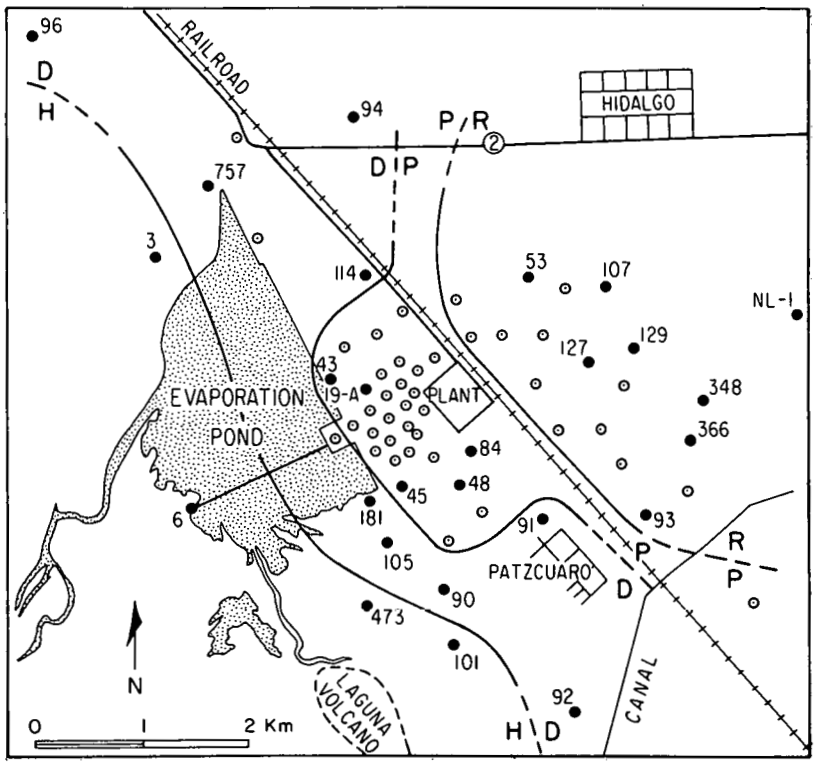


FIGURE 1 Map showing the inferred division of the Cerro Prieto geothermal field into regions of characteristic flow regime. The small circles show the locations of deep wells, only a selection of well numbers is shown.

The four flow regimes are:
R-recharge zone,
P-thermal plume zone,
D-discharge zone,
H-horizontal flow zone.

Using the criteria listed above we have divided the field into four regions of different flow types. These are a recharge zone (R) where cold water is descending; a thermal plume (P) where hot, boiling water is rising; a discharge zone (D) where rapidly cooling water is discharging to the surface; and lastly a zone of subsurface horizontal flow (H), characterized by temperature reversals in the wells which penetrate it. We postulate on this basis that the thermal plume is elongated in a NW-SE direction and is inclined at 45° to the NE. The heat source which feeds it lies in that direction, with hot water discharge to the SW, and recharge from the NE. This model, based only on these petrologic indicators, is being tested by drilling of 3 km deep wells in the NE part of the field.

Our work at Cerro Prieto was supported by the DOE under Contract No. 7100410 from Lawrence Berkeley Laboratory.

GEOLOGY OF LOW- AND INTERMEDIATE-TEMPERATURE HYDROTHERMAL SYSTEMS

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Low- (<90°C) and intermediate-temperature (90°-150°C) hydrothermal systems have received less attention in the geothermal literature than their high-temperature counterparts. Notable exceptions are the resource, development, and institutional background provided by Anderson and Lund (1979) and the resource cataloging by personnel of the U.S.G.S. (Brook and others, 1978; Sammel, 1978). However, because of the efforts of the Division of Geothermal Energy of the Department of Energy to promote direct heat utilization, exploration for these resources will increase in the near future.

Brook and others (1978) have shown that the number of geothermal systems increases exponentially with decrease in temperature for systems with reservoir temperatures greater than 90°C. Although the data have not as yet been compiled, it is thought that this trend will continue for systems of less than 90°C.

This paper discusses conceptual models of low- to intermediate-temperature hydrothermal systems. Although individual systems will have unique geologic aspects, an understanding of common denominators is an important step in formulating exploration procedures. The discussion will not include geopressured systems or waters which are peripheral to high-temperature systems and have cooled by mixing or conduction.

The heat for low- to intermediate-temperature hydrothermal systems is provided by the earth's geothermal gradient. This is commonly in the range of 10° to 45°C/km with a crustal average of about 30°C/km. Zones of anomalous heat are often developed in areas of recent tectonic and volcanic activity, by the presence of high concentrations of radioactive elements, or by the insulating effects of rocks with low thermal conductivity. Given an average crustal gradient of 30°C/km, a temperature of 90°C is reached at about 2650 meters, and temperatures of 150°C are achieved at about 4650 meters.

The permeability of rocks in the system controls the flow of fluids to depth and their ascent toward the surface. This permeability is provided by fault and fracture zones, stratigraphic horizons, or a combination of both (Mase and others, 1978; Bedinger and others, 1979; Hobba and others, 1979). The geometries of the systems and flow paths of the fluids are unique for individual systems. Fault zones provide the most direct channels by which the heated fluids are brought to the surface. This may result in the fluids discharging as hot springs, or faults may channel fluids into a stratigraphic horizon during their ascent. However, faults may act as aquicludes as well as aquifers. The permeability of a fault is dependent on the character of the brecciated material along the zone (i.e., gouge, breccia) as well as units juxtaposed by the offset (Smith, 1980). The flow of water through these systems is a response to a combination of heat (forced convection) and free convection in the presence of a temperature gradient, with

the latter being of greater importance in the higher temperature systems.

The fluids found in low- to intermediate-temperature hydrothermal systems show a broad range of quality. Within individual systems there is often a positive correlation between temperature and total dissolved solids. However, in addition to temperature, the chemistry of the hydrothermal fluids may be strongly influenced by the types of rocks in the system, by mixing with connate and other meteoric waters, and by membrane effects.

The metamorphic reactions which take place in low- to intermediate-temperature hydrothermal systems are important in controlling permeability and fluid paths, indicating the general temperature of the system, and producing phases which can be detected by electrical geophysical exploration methods. Alteration reactions can begin at normal surface temperatures and depend strongly on the compositions of both rock and fluid phases. At lower temperatures the kinetics of reactions are extremely important, and many of the assemblages produced are not in thermodynamic equilibrium. Montmorillonite and mixed-layer clays begin to form in the diagenetic environment and are stable past temperatures of 150°C. Zeolites are important products of the alteration of volcanic material forming at temperatures of 30° to 60°C and persisting to temperatures of 140° to 180°C depending on the species present.

The abundance of low- to intermediate-temperature hydrothermal resources suggests the potential for a large thermal energy contribution to the nation's needs. The systems are controlled by structural and stratigraphic permeability and derive their heat by the circulation of waters to depth. These waters are of variable quality and react with the wall rocks to change both their chemistry and the minerals present in the wall rocks. Exploration must proceed from these general concepts to the consideration of the unique aspects of the individual systems.

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FLUID GEOCHEMISTRY AND GEOTHERMOMETRY

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Geothermal systems, now of interest as exploitable energy sources, provide direct observation of chemical processes that can be studied elsewhere only in fossil states exposed by erosion. The velocities of chemical reactions increase with temperature and with the presence of liquid water. Consequently, hydrothermal systems where fluid convection has transferred heat from deep in the earth to shallow reservoirs are windows into deep earth processes. However, observation of these systems is limited to 3 to 4 km by economics and by our present ability to drill in hostile environments. The liquid-vapor equilibrium curve of boiling saline water limits temperatures and pressures at these depths to about 400°C and 250 bars. High temperature magmatic and metamorphic processes are therefore still not directly observable.

Chemical processes in geothermal systems result from the movement of heat and fluid. No geothermal system transferring heat to the surface can be isothermal, and temperatures increase with depth along (low) conductive or (high) convective gradients. In hot-water geothermal systems temperature gradients may be large. Convective gradients greater than 160°C in 60 m have been measured at shallow depths in Yellowstone; temperature gradients of 80°C in 1200 m vertically and 1500 m horizontally exist in the exploited reservoir of Cerro Prieto. Large changes in chemical equilibria occur over these temperature ranges and, as a result, fluid movement must transfer mass as well as heat.

The character of mineral-water reactions depends largely on solubilities. Chloride salts are so soluble that, except in hypersaline brines, all chloride remains in the fluid and accumulation in solids does not occur. Other less soluble substances (e.g., SiO_2) may be dissolved in high-temperature parts of geothermal systems, moved long distances, and deposited at lower temperatures. The least soluble substances (alumino silicates--feldspar, mica, etc.) may be transported slowly but are usually altered by recrystallization in place, often with ion exchange of some components (Na^+, K^+, Ca^{++}, etc.) carried in the fluid. Temperature gradients and mass transfer by convecting fluids result in mineral zonation within geothermal systems.

Thermal gradients are only one factor producing chemical changes in geothermal systems. Most temperature changes in ascending fluids result from boiling or mixing with cold waters, and these processes also produce chemical changes. Boiling causes segregation of dissolved gases into steam and salts into residual water. Loss of dissolved CO_2 produces increase of pH and deposition of calcite. Increase of pH also causes deposition of sulfide (usually pyrite) as H_2S is converted to HS^-. Mixing with aerated cold waters oxidizes H_2S to SO_4. Mixing (and heating) of calcite-saturated cold water with thermal water can produce further deposition of calcite. The reaction of CO_2 with Na silicates produces clay minerals and Na^+ and HCO_3^- in solution. High temperature thermal waters exchange K^+ for Na^+ in silicates at lower temperatures to increase Na/K ratios.

All of these chemical changes add complexity to the study of fluid and solid samples from geothermal wells. They also provide means of estimating deep temperatures and fluid flow directions from shallow samples of fluid. The rates of chemical reactions decrease with decreasing temperature, so ascending fluids (if cooled rapidly enough) partially or wholly retain higher temperature equilibrium conditions. These "frozen-in" equilibria provide quantitative geothermometers (silica and Na-K-Ca) to indicate subsurface temperatures and qualitative indexes (HCO_3/Cl, Ca/Na) to subsurface flow directions. During ascent from temperatures greater than 200°C, when even the best geothermometers undergo reequilibration, the subsurface temperature information may be "quenched" by subsurface mixture of cold and hot fluids and then can be calculated from mixing models. The known complexity of subsurface chemical processes suggests that none of these methods should be applied in a "cookbook" fashion without consideration for local geologic and hydrologic factors.

Vapor-dominated geothermal systems differ chemically and physically from hot-water systems. In the vapor-dominated reservoir, lateral and vertical temperature gradients hardly exist. Permeability to steam is high, steam flows readily to decrease lateral pressure gradients, and only slight vertical pressure differences exist. The presence (before exploitation) of both liquid water and steam throughout the vapor-dominated reservoir (except perhaps in local venting zones) ensures similarly small temperature gradients. The insolubility of salts in steam and the relative immobility of liquid water suggests that, except for silica carried in descending condensate, mass transfer is relatively limited. Only gases from the reservoir reach the surface, and the use of chemical geothermometers is thereby very restricted. The temperatures of these systems are, however, usually close to 240°C; and geothermometers may not be necessary. Recent interpretation of areal variations in gas, isotope, and volatile salt concentrations in steam from vapor-dominated systems suggests that before exploitation the dominant process was lateral (centrifugal) steam movement. Central zones of boiling (or steam upflow) were limited in area and most of the reservoir was occupied by steam flowing laterally toward the edges of the system, losing heat by conduction to the surface, and progressively condensing until exhausted. Because of the condensation, gas contents increased and salt (and oxygen-18) concentrations decreased as the steam flowed laterally. Leaching of rock minerals by condensate may be responsible for the large lateral extent and cavernous porosity of these systems. The chemical gradients remain after exploitation and may be of value in locating productive zones.

During field development, the chemistry of fluids (and rocks) continues to be useful in indicating the properties of the reservoir--size, temperature, and porosity distribution--and in anticipating problems of scaling and corrosion. Chemical monitoring during production provides data useful in determining fluid flows, cold water intrusion, aquifer boiling, and other effects of exploitation.

GEOCHEMISTRY OF SOLIDS IN GEOTHERMAL SYSTEMS

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The geochemistry of hydrothermally altered rocks is routinely used by the minerals exploration industry as a guide to buried ore deposits. Yet, despite the similarities between hydrothermal ore deposits and active geothermal systems, the development of geochemical zoning models by the geothermal industry has been largely neglected. Recent studies by Bamford and others (1980) and Christensen and others (1980) have, however, demonstrated that the geochemistry of drill cuttings and soils can indeed be applied to geothermal exploration. For example, these studies indicate that even weakly altered samples can be used to determine the size and shape of the geothermal system as well as the distribution of permeable faults and fractures. This paper illustrates how geochemical studies of solids have been used in the evaluation of the Roosevelt Hot Springs geothermal system.

The Roosevelt Hot Springs thermal area is located in south-central Utah in an area of recent rhyolitic and basaltic volcanism, (Lipman and others, 1978). The reservoir rocks consist of fractured Precambrian gneiss and Tertiary granite which underlie alluvium on the western flank of the Mineral Mountains (Nielson and others, 1978). Seven production wells have been drilled since 1974 and Ward and others (1978) estimate that the wells are capable of producing approximately 4.5×10^5 kg/hr of steam and water. The reservoir fluids have a temperature of about $260^{\circ}C$.

The geothermal fluids are dilute sodium chloride brines containing approximately 7000 ppm TDS and anomalous concentrations of fluorine, arsenic, lithium, boron and mercury. Interaction between the geothermal fluids and the reservoir rocks has resulted in the concentration of mercury, arsenic and lithium along the fluid pathways (Bamford and others, 1980; Christensen and others, 1980). Locally, these pathways are marked by intense argillic alteration, silicification and pyritization. Downhole geophysical data and temperature profiles suggest that these channels are steeply dipping fracture zones (Glenn and Hulen, 1979). The geothermal fluids are presently being tapped at several locations along these fracture zones.

Comparison of the trace element distributions indicates that the deposition of arsenic and lithium begins at higher temperatures than the deposition of mercury. Mercury anomalies occur in the outer portions of the geothermal system and extend to depths marked approximately by the $215^{\circ}C$ isotherm. The mobility of mercury was studied by measuring its concentration in a suite of progressively heated samples from the thermal area. These experiments showed that approximately 90% of the mercury is lost by the time the samples reach temperatures of $250^{\circ}C$. Christensen and others (1980) have suggested, based on the results of these experiments, that the distribution of mercury in the thermal area reflects the present thermal patterns. Leaching of previously deposited mercury, and its redeposition in cooler environments, may be an effective concentrating mechanism in the Roosevelt Hot Springs geothermal system.

Concentrations of mercury and arsenic in soils from the thermal area form a series of northeast- and northwest-trending anomalies that mark the trend of faults and fractures which are hydraulically connected to the geothermal system (Bamford and others 1980; Capuano and Moore, 1980). These trends parallel the major fault directions mapped by Nielson and others (1978) on the western flank of the Mineral Mountains. Hot spring deposits and arsenic anomalies up to 10 times background occur at the intersection of the northeast- and northwest-trending zones where fluids have discharged at the surface. Mercury is more widely dispersed, reflecting its mobility at lower temperatures.

The isotopic composition of solids and fluids from the geothermal system have been studied by Rohrs (1980). These data suggest that the fluids are meteoric in origin and could be derived from nearby mountain ranges. Within the reservoir, the whole rock, potassium feldspar, and biotite ^{18}O contents are closely related to the intensity of alteration. Calculations based on these data suggest that relatively impermeable zones associated with weakly altered rocks are characterized by water/rock mass ratios between .1 and .3, whereas strongly altered rocks in more permeable zones are characterized by ratios between 1.4 and 3.

ACKNOWLEDGEMENTS

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GEOTHERMAL GEOPHYSICS

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Because the geothermal industry is in an infant stage in this country, exploration strategies are far from optimum. Geophysical equipment and techniques have been adopted from the petroleum and mineral industries for application to geothermal exploration and reservoir assessment problems, and, while some success has been obtained, it is evident that geophysical tools developed specifically for geothermal application are needed. This paper briefly reviews the major physical and chemical properties of the hydrothermal geothermal environment that potentially lend themselves to remote geophysical detection and then discusses individual geophysical methods.

Hydrothermal temperatures of interest vary from somewhat above a mean ambient groundwater temperature of 10-25° to well over 300°C. The higher temperatures are usually found in systems whose heat source is a young intrusion of magma into the shallow crust. Fluids range in salinity from relatively fresh, as at Beowawe, NV to saturated as in some of the Imperial Valley, CA systems, and dissolved constituents include the common salts, a host of trace elements such as As, Pb, Zn, and W, volatile elements such as Hg, and gasses such as CO_2, H_2S, and Rn. Some hydrothermal systems are small, being confined to a few acres where fluid rises along a fault, whereas some are large, as at The Geysers, CA, or the Madison group of thermally anomalous aquifers that cover broad areas in North and South Dakota, Montana, and Wyoming. In most hydrothermal systems the flow of fluids underground is controlled to a much greater extent by fracture-developed permeability than by primary permeability. Structure is complex in many hydrothermal systems. In most systems, particularly those of higher temperature, circulating fluids have caused hydrothermal alteration and mineral deposition in fractures of the host rock that is sometimes zoned around the heat source. Each of these physical and mineralogical features can, under proper conditions, produce an anomalous condition that is remotely detectable by geophysical means.

The geophysical techniques often described by industry as being most helpful are thermal techniques. Both temperature/temperature gradient and heat flow determination can be useful in directly detecting the resource. Boreholes must be deep enough to be unaffected by cool water overflow, which can mask anomalies from depth, and the problems of extrapolating temperature to depth are legend. New techniques for simultaneously modeling hydrology and heat flow data promise better reliability and resolution in remote detection of geothermal systems.

The electrical techniques have proved useful in a number of environments. Generally the vicinity of a hydrothermal resource is characterized by a relative resistivity low due to (1) deposition of electrically conducting hydrothermal minerals such as clays and zeolites, (2) the salt content of many geothermal fluids, and (3) the anomalous temperature, which causes lower fluid resistivity through higher ion activity. Galvanic resistivity, magnetotelluric and electromagnetic techniques are all capable, under proper conditions, of mapping this low resistivity. The induced polarization technique is capable of detecting certain

hydrothermal clay and sulfide minerals deposited along fractures, but field results to date in geothermal areas have been disappointing. The spontaneous potential method appears promising, but adequate interpretation techniques are lacking. It is apparent that in many hydrothermal systems, 3-dimensional electrical interpretation techniques are required. The complex mathematical formulations necessary to implement these techniques are still under development and more work needs to be done.

The gravity technique has been useful in detecting deposition of silica in zones of scaling above certain reservoirs in the Imperial Valley, CA. It also finds general use in helping to delineate both broad crystal structure and structure within geothermal areas. New very high sensitivity cryogenic gravity meters under development appear promising for measuring mass withdrawal during production of hydrothermal systems.

The magnetic method finds application in helping to map regional and local geology including rock type and structure. Some hydrothermal systems may have an associated magnetic low due to local destruction of magnetite by hydrothermal alteration, but this is not well documented at present.

Seismic techniques may be divided into active methods, having a man-made energy source, and passive methods, having a natural source. The active techniques generally are expensive and can be difficult to run in rugged terrain, although they hold promise of detailed structural delineation at depths of thousands of feet. Development of equipment, field and interpretation techniques capable of higher resolution than is needed for petroleum exploration would prove fruitful in geothermal exploration and detailed reservoir delineation. The passive techniques are used to detect minor adjustments and flow of fluid in the hydrothermal reservoir.

GEOTHERMAL EXPLORATION

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Data available in the years 1975-1978, inclusive, indicate that the success ratio for geothermal wildcat wells is approximately half that for oil and gas wildcats in the U.S. (Nielson, 1979). In terms of total geothermal and oil and gas wells drilled, oil and gas has a slightly better record. This might be considered a discouraging portent of the difficulties facing the geothermal industry, particularly from the premise that the industry is young and it is the easy prospects that are being found, contrasted with an oil and gas industry, past maturity, obliged to find the remaining small accumulations tucked away in deep dark places.

Fortunately, the record does not warrant such a dismal outlook. During the time since Drake's well, 1859, the long term trend has been an improving success ratio in wildcat drilling for oil and gas. In 1979 an all time record was set at 18.12 percent as well as a new record in all exploratory wells at 28.84 percent (Oil & Gas Journ., Aug. 4, 1980). Part of this record is doubtlessly due to the fact that some successful wells in 1980 would have been considered marginal in times past. This same factor, however, will affect the geothermal industry, particularly as experience permits us to make full utilization of lower quality resources. Another contributor to the improving oil and gas success ratio is an exploration technology that is continually reaching new levels of sophistication. We may confidently expect the same improvements in geothermal exploration technology, to the extent there is a demand for the resource.

Some gaps in current exploration technology are known, and future R&D efforts should be concentrated in these and other areas as they are identified.

Volcanic Cover - Extensive areas having high geothermal potential are covered with Late Cenozoic volcanics, examples being the eastern Snake River Plain, Idaho, the high Cascades, and Hawaii. While the young volcanics themselves attest to the potential, the nature of these rocks are such that focus is difficult to achieve in an exploration program. Signals in active seismic surveys are effectively scattered and absorbed by the fragmented, autobrecciated rock, heat flow is nonconductive with water freely percolating through the fractured mass, conventional geologic methods are of little avail owing to the extensive cover and springs are at best highly diluted with shallow meteoric water.

Blind Reservoirs - Reservoirs having some surface indication of their presence, recent volcanics, hot springs, fumaroles, etc., are finite in number, and soon each will have been evaluated one or more times by competing firms. While some of these will need to be "revisited" in the future, exploration programs should be gearing up to find the blind reservoir. Bearing in mind that some targets will be less than a township in size areally, a method or package of methods are needed to provide a cost effective, quick look over large areas.

Hydrology - Groundwater movements affect all heat flow and other geophysical measurement from lesser to greater degree. Integrating hydrologic data with other field measurements has not generally been undertaken with an effective commitment by most of the exploration fraternity. Possibly most of us do not yet realize the

magnitude of the problem.

Fracture Mapping - Inasmuch as most reservoirs are, in the main, a system of fractures in tight rock, locating fracture systems is of paramount importance in siting the first deep test and in field development. The hot dry hole less than 100m from the best producer in the Ahuachapón field, El Salvador is a too common occurrence.

The most effective Research and Development is in borrowing technology from sister sciences and modifying to solve the particular problems at hand. Accordingly, some on stream methodologies may be effective in solving some geothermal exploration and development problems. Vertical Seismic Profiling (VSP), (Gal'perin, 1974), wherein a seismic source is placed at the surface and 3-component detectors are positioned at close intervals in the borehole, may through a study of the compressional and shear waves identify reservoir fractures. Moreover, with a moving seismic source velocity and attenuation anisotropy, expressing preferred directions of fractures, can be recorded. Moreover, with VSP data one may look deeper into the subsurface than the bottom of the borehole. Deep active seismic sounding, following COCORP techniques, may identify shallow reservoirs. Deep fault systems have been mapped to the lower crust and magmatic processes involving deep crustal rocks have been interpreted in the seismic sections. Relatively shallow geothermal reservoirs should have a clear spatial relationship to the deeper magmatic or fault system to which they are genetically tied. Full waveform sonic logging is a proven method of determining rock physical properties. Poisson's ratio derived from the compressional and shear information in the record will identify reservoir fractures and provide useful information on the lithology behind the borehole. Data acquisition systems have been fully automated so that computer assisted interpretations are available at the well site to aid in guiding decisions on further drilling, testing and well completion. Bit location techniques, now becoming operational, use coherent energy in the bit grinding noise to locate the bottom of the hole with hypocenter location methods. Velocity anisotropy, expressing fracture trends, will be revealed in the data.

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GEOTHERMAL WELL LOGGING - THE STATE-OF-THE-ART

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Well logging is an indispensable activity during geothermal energy exploration and development. While well logging has been practised in the petroleum industry for five decades, it is a relatively new field of activity in the geothermal industry. There are two basic types of problems associated with geothermal well logging: hardware-related problems and interpretation-related problems. These problems arise from the fact that well logging was developed in the petroleum industry where wells are much less hot (less than 150°C) and encounter sedimentary rocks with mostly intergranular porosity. Geothermal wells on the other hand are often hotter than 150°C and usually encounter igneous or metamorphic lithology with fracture porosity.

Usually a geothermal well is cooled down by mud circulation and then standard petroleum well logs are run. However, if a well cannot be cooled down sufficiently, most logs cannot be run. Sandia Laboratories of U. S. DOE and the logging service companies have recently developed some high temperature logging tools for geothermal wells; others are still being developed. Even if a successful log can be run in a geothermal well, it may be difficult to interpret it quantitatively, because most of the interpretation techniques developed for petroleum wells do not apply in the fractured, non-sedimentary conditions of a geothermal well. The typical interpretation problems arise due to lack of calibration data of well logs for non-sedimentary lithologies. Los Alamos Scientific Laboratory of U.S. DOE has recently established calibration wells and test pits for goethermal logging tools. The lithology in a geothermal well can have infinite variations with depth. Hence the responses of a well log to the lithology on the one hand, and porosity and fluid content on the other cannot be easily distinguished. Detailed petrophysical models for geothermal formations are lacking, making quantitative interpretation difficult. The possible effects of elevated temperature and the chemistry of geothermal fluids on well log responses are not thoroughly known.

Notwithstanding these difficulties, geothermal well log interpretation is evolving rapidly. Los Alamos Scientific Laboratory has recently issued a report on the state-of-the-art of geothermal well log interpretation (Sanyal, Wells and Bickham, 1979, Final Report, Subcontract No. X48-96245-1, LASL). This report discusses the various problems in geothermal well logging, provides a classification of geothermal reservoirs from the viewpoint of logging, gives an exhaustive literature survey, examples of quantitative interpretation,gives a compilation of matrix data for various lithologies and proposes a number of petrophysical models for geothermal reservoirs. That report and the recent publications indicate that it is indeed possible to interpret geothermal well logs, qualitatively if not quantitatively. The author has successfully applied geothermal well logs in exploration and development for many years. The attached table summarizes the author's experience on the utility of the various log.

UTILITY OF VARIOUS WELL LOGS IN NON-SEDIMENTARY LITHOLOGY

LOG TYPE	COMMENTS
1. Self Potential	Often poorly developed; Unreliable in massive igneous or metamorphic sections; Works in some fractured igneous and metamorphic sections; Usually not useful for correlation.
2. Electrical Resistivity	Mostly off scale in massive igneous and metamorphic sections; Can be helpful in locating fractures Short spacing resistivity may be affected by the short-circuiting effect of borehole fluid; Focussed devices may be helpful for very resistive formation.
3. Acoustic Devices	BHC sonic log works well unless there is significant hole enlargement; May be useful for correlation; Matrix velocity values may not be known; Useful for overlay and crossplot techniques; Full-wave sonic log valuable in locating fractures; Borehole televiewer valuable for locating fractures and delineating its orientation; Frac finder log may be useful.
4. Neutron Devices	Responses from unfamiliar lithology may be difficult to assess; May be useful for correlation.
5. Density	Useful in estimating porosity and lithology; caving may be a problem; Log response from unfamiliar lithology difficult to assess; Useful for correlation.
6. Gamma Ray	Useful for correlation; Spectral gamma ray useful for lithology identification.
7. Drilling Log	Drilling rate log useful for locating fracture zones and changes in lithology; Drill cuttings log useful for lithology identification; Useful for correlation.
8. Caliper	Useful in resolving many log quality problems; 6-arm caliper can be used in determining dip of fracture-zone washout; Use in judging hole condition.
9. Dip Meter	Not always useful because of lack of laminated structure; Dip of fractures may be unreliable.
10. Temperature	Useful for assessing temperature gradient, and other standard uses of temperature log.

HIGH TEMPERATURE GEOTHERMAL RESERVOIR ENGINEERING

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High temperature geothermal reservoirs are regions in the drillable portion of the earth's crust that contain recoverable thermal energy at mean temperatures greater than roughly 150°C.* The objective of high temperature geothermal reservoir engineering is to recover the heat of the reservoir--effectively and economically. To achieve this objective, reservoir engineers have two fundamental responsibilities:

1. to understand the nature of the reservoir, including the distribution of temperature, pressure, porosity, salinity of fluid, and permeability within the reservoir; and
2. to forecast the response of the reservoir, particularly its productivity, when it is disturbed by production and injection wells.

The reservoir engineer is also the key advisor to the business and financial community regarding the optimal rate and total amount of heat that a reservoir can yield.

A variety of measurements are made to define the location and internal characteristics of a reservoir. Prior to any deep drilling, observation of the geochemistry of hot springs, of surface geology, of measurements of elastic and electric properties of the earth and of heat flow lead to preliminary definition. For example, the occurrence of heat flow significantly above the global average would suggest--but not prove--the presence of a geothermal resource. Deep drilling followed by in-hole logging of temperature, pressure, and physical properties of rocks (e.g.seismic velocity) and direct observation of drill cuttings provide a more detailed but still limited understanding of a reservoir. For example, the occurrence of certain minerals in cuttings will, in some cases, indicate reservoir temperatures greater than 250°C, a conclusion that can be cross checked by direct temperature measurement when the drill hole reaches temperature equilibrium with the reservoir. Porosity, that is the ratio of fluid filled voids to bulk volume, can be estimated from seismic velocity readings and electrical resistivity readings of short sections of drill hole. Fluid salinity is determined from chemical analyses of produced fluids and is important in several ways. Chemistry, if properly interpreted, reflects the temperature of the reservoir. In addition, certain chemical systems (e.g. the carbonate system) adversely affect reservoir development because they lead to scaling and precipitation within well casing, near the well vicinity, and in surface collection pipe. Planning for development must take into account such chemistry related problems.

Changes in pressure due to production or injection of a subject well or of nearby wells, as analyzed by specialists in "well test analysis", are the basis for evaluating the hydraulic properties of a reservoir. Most reservoir engineers consider this subject and performance simulation (see below) to be the core of reservoir engineering. Analysis can be made of pressure transients either downhole or at the wellhead, where instrumentation is, perhaps, easier to manipulate. For high temperature reservoir engineering, however, phase changes from liquid to liquid plus vapor

*The choice of temperatures greater than 150°C follows the practice of the U.S. Geological Survey. The fact that temperatures are high enough to cause two phase flow phenomena that cannot be ignored is perhaps the most significant distinction between "high" and "low" temperature geothermal reservoirs.

as fluid moves out of the reservoir and up the bore makes the interpretation of surface measurements less tenable than those of in situ downhole measurements. Downhole instrumentation for use at temperatures above 150 - 200°C is currently being perfected and developed and is vital, obviously, to the measurements needed for reservoir engineering.

Data about a geothermal reservoir, like almost any natural resource, are always less than one would desire. Thus, it is necessary to make an interpretation of a whole geothermal system largely through the use of simplified conceptual models. Conceptual models for all subsurface natural resources are usually based on case histories for analogous or similar, extensively drilled and studied examples. Those most applicable to geothermal resources are thought to be hydrothermal mineral deposits. Geothermal resource development itself has only a limited body of experience with which to build a series of valid models. Such syntheses are an especially important need today.

Forecasts of the performance of a geothermal reservoir are based on physically valid, mathematical models that are solved either analytically or with computers using various numerical methods. Performance simulation is complicated not only because transport of both heat and mass must be treated simultaneously but because phase changes can occur in the reservoir fluid. For example, two phase flow requires modeling the transport of two fluids: the two fluids have different viscosities, can transform one into the other, and the abundance of each phase can affect the relative permeability of the reservoir to its flow as well as to the flow of the other phase. Several computer codes for reservoir performance simulation of high temperature geothermal reservoirs now exist.

Transport and modeling of chemical species, which are significant in the behavior of high temperature geothermal reservoirs, is still another complication currently being addressed by experts in geothermal reservoir performance simulation.

Progress in high temperature geothermal reservoir engineering has been significant in the last five years owing to increased interest in the exploitation of such resources by the private sector and to substantial support from the Department of Energy/Division of Geothermal Energy. At this time it seems that a great many techniques for measurement, analysis, and forecasting have been developed. We are now entering a period that should be characterized by extensive application of these techniques with a view to evaluating their utility and to improving them in view of experience gained through application.

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TESTING AND ANALYSIS OF LOW-TEMPERATURE HYDROTHERMAL RESERVOIRS*

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The goal of geothermal reservoir engineering is to determine the "economic yield" of a geothermal resource. Economic yield is defined as the maximum volume and flow rate that can be withdrawn from a reservoir over the life of a project without excessive drawdown of the well field, unacceptable temperature changes, adverse effects on other resource users, or deterioration of the local aquifers.

Well testing and calculating the economic yield of hydrothermal reservoirs involve different techniques and procedures than are used to determine the capacity of non-thermal reservoirs because conventional theories assume that (a) fluid flow is intergranular, and (b) fluid flow in both the wellbore and the aquifer are isothermal so that viscosity and density are constant. This is not usually the case with hydrothermal reservoirs. Unless these variables are considered, calculations of aquifer coefficients will be inaccurate, although they can provide useful order-of-magnitude estimates if interpreted broadly.

Well Testing. The objectives of well testing in either an ideal non-thermal aquifer with intergranular permeability or a hydrothermal reservoir with fractured rock are to characterize well response, determine resource characteristics, and project reservoir longevity. These objectives are accomplished by (a) stressing the well by pumping or injecting, (b) calculating aquifer coefficients by using either standard water well or petroleum techniques, or methods specific to hydrothermal reservoirs, and using the coefficients to predict reservoir longevity.

During pumping or injection for a hydrothermal well test, pressure, flow rate, and temperature are measured. Instruments to make these measurements accurately in a thermal environment are often costly or unavailable. Off-the-shelf equipment can be used to collect useful data, however, if the test procedures are modified to include wellbore preheating, long-term testing, and pulse testing. Preheating the wellbore (flowing the well under artesian low-flow conditions) reduces the effects of temperature changes on early time data. Long-term tests are more effective than short-term tests because non-isothermal water flow often dominates short-term tests, particularly if multiple production zones are tapped. Varying the flow rate in a step drawdown test changes thermal/flow conditions, but pulse testing reduces this problem.

For most fractured hydrothermal reservoirs, anisotropic analysis is recommended for which at least three fully penetrating observation wells are necessary. New computer techniques may make data from one or two wells useful.

Problems encountered during production testing of hydrothermal wells include (a) failure of instruments in thermal or poor quality water, (b) disposal of hot

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brines, (c) failure of wellhead or piping systems due to temperature or pressure, and (d) maintaining a quiet well field during testing. Problems of injection testing include (a) the injected fluid must be filtered to remove suspended solids and prevent well clogging, and (b) inaccurate data caused by temperature differences between the injected fluid and the projected effluent.

Well Test Analysis. Stressing a well by pumping or injection lowers the piezometric level. This is called drawdown, and is the maximum point of a cone-shaped decline in pressure (cone of depression). The magnitude of drawdown and the shape of the cone depends on aquifer transmissivity (T), which is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit of hydraulic gradient. The storage coefficient (S) is the volume of water released from the aquifer under a unit change in head, and is related to the compressibility of the aquifer and the fluid.

Analysis of well test data involves calculations of T and S. Theis developed a non-steady-state solution to the flow equation that depends on the assumptions that (a) the aquifer is homogeneous and isotropic, (b) the aquifer is infinite in areal extent and the well is infinitesimal in diameter, (c) the aquifer is confined and the well is fully penetrating, (d) fluid flow is isothermal, and (e) water is removed from storage instantaneously with decline in head. Jacob modified this solution so that an arithmetic straight line plot of drawdown (s) versus the logarithm of time (t) can be used to calculate T and S.

Because the coefficient T depends on both matrix and fluid properties, the early portion of the log t versus the s curve, when temperature changes cause fluid properties to change, does not plot on a straight line. Thermal effects may cause a rise in wellhead pressure for the duration of a short test (Fig. 1). Differences in fluid properties in different zones of the aquifer may cause apparent "boundary effects," which change the slope of the curve. This is more apparent during injection testing. Different fluid temperatures in zones contributing to flow may cause non-linear variations in wellhead pressure.

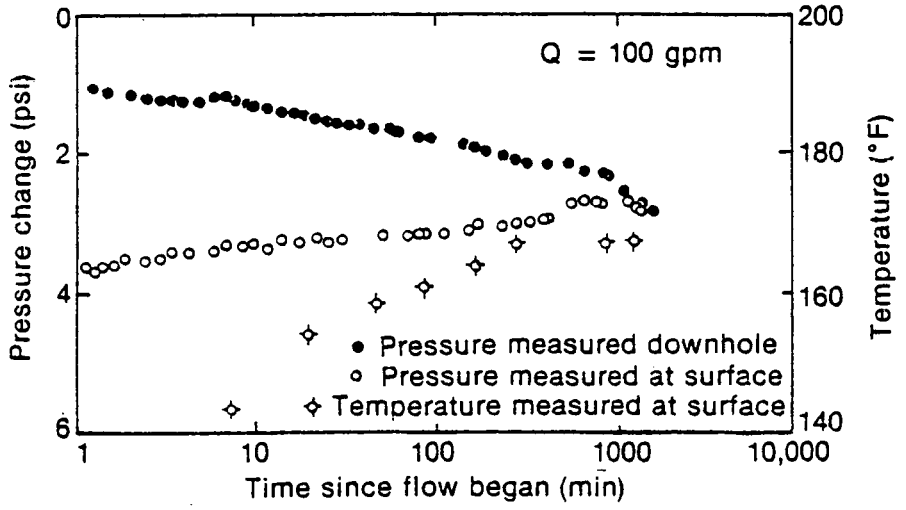


Fig. 1. Semilog plot of flowing BHW-1 well pressure response. Boise, Idaho, October 28-29, 1976.

When calculating coefficients using Theis' or Jacob's solution, these problems should be considered for predictions of long-term well behavior. The presence of formation fractures should also be considered. A practical approach may be to pump or inject at a rate equal to or greater than the intended use and extrapolate the semilogarithmic straight line segment.

INTERFERENCE TESTING IN GEOTHERMAL RESERVOIRS

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The initial assessment of geothermal reservoirs usually has two main objectives. One is determination of the deliverability rate from the reservoir, and the other is estimation of the reserves, or the economically producible amount of steam in the system. Many geothermal reservoirs are complicated by the fact that neither the porosity-thickness product nor producible area are known, either early in the life or after extended production. The most reliable means of determining the deliverability is usually a pressure transient test. Pressure transient tests can be conducted in a reasonably short period of time, and early in the life of a geothermal development. However, estimation of steam reserves usually requires an extended period of production with observation of mean reservoir pressure at various stages of production. Material and energy balance performance matching with a detectable decline in pressure following production is the minimum information for performance matching. Thus it is necessary to produce a reservoir for an extended period of time before performance matching can be accomplished with reasonable precision.

The dilemma is that single well pressure tests of fairly short duration are needed to provide information on deliverability (permeability thickness or transmissivity) and well condition, while long-term production testing is required to establish reserves. Fortunately, an interference test is a type of pressure transient test that can be accomplished in a reasonable period of time, and yet provide important information concerning apparent reserves early in the life of a geothermal development. At least two wells are required for an interference test.

The main problem with single well pressure transient tests is that distances in the reservoir are measured in units of the wellbore radius. A test of an individual well can yield important information concerning the condition of the well, the formation, conductivity, and drainage boundaries of the well. However long periods of production are required prior to the pressure transient testing for boundaries to be evident when distances are measured in units of wellbore radii. An alternative procedure is to observe pressure effects transmitted between two or more wells. This kind of test is usually called an interference test. The theory of interference testing was originally explained by C.V. Theis (1935). A modern discussion of interference testing procedures has been presented by Earlougher (1977). There are many recent publications on this important subject in both the groundwater and the petroleum engineering literatures. An example of application of interference testing to geothermal systems has been published by Chang and Ramey (1979).

One simple basis for interference test analysis is the continuous line source solution. This model assumes that a single well is produced starting at time zero at a constant rate in an infinitely large reservoir of constant properties. The pressure effects caused by the producing well may be observed at one or more distant wells which are not produced but used simply as pressure observation stations. The solution to this problem can be displayed on a piece of log-log coordinate paper. Figure 1 is a type-curve for this problem used commonly in the petroleum literature. Figure 1 presents a dimensionless pressure which is directly proportional to an observed pressure drawdown versus the ratio of a dimensionless time to the dimensionless distance between the produced and observation well squared. The dimensionless

time is directly proportional to real time, and the dimensionless distance is directly proportional to real distance. An important characteristic of the logarithmic scale is that quantities proportional to the plotted scale are simply displaced linearly along the scale. Thus it is possible to graph the field data observed in an interference test as a pressure drop on the ordinate versus time on the abscissa, and make a direct comparison with the analytic solution represented by Fig. 1. This procedure is called log-log type-curve matching, and has been outlined in detail in many references, such as Earlougher (1977).

Once a set of field data has been matched with the line source type-curve, it is possible to equate the pressure difference point with the dimensionless pressure from the type-curve to make quantitative calculations. In the usual case, the net formation thickness (h), the flowrate (q), the formation volume factor (B), and the viscosity (μ) of the produced fluid would be known. The objective of the pressure matchpoint would be calculation of the effective permeability to the flowing phase (k). From the time matchpoint, it would be possible then to calculate the porosity-compressibility product. In the ordinary case, the porosity would be known, and thus it would be possible to obtain a check on the average compressibility of the formation and fluid. An alternative would be to determine the in-place porosity under the assumption that the average compressibility of the rock-fluid system were known. This step is frequently done in petroleum engineering work as a check upon porosity derived either from core analyses or from well logging methods. In petroleum engineering application, one frequently obtains both effective permeabilities and porosities which agree with information known from other sources. For example, the effective permeability will frequently agree with that obtained from a pressure buildup test on a single well, while the porosity obtained from an interference test will frequently agree with porosities obtained from core analyses.

In the case of interference testing of geothermal systems, analysis is often more complex. In the use of pressure matchpoint, it is often observed that the net formation thickness for the geothermal system is not known. This may be a result of the fact that the geothermal formations have not been fully penetrated by drilling, or that the geothermal system is a fractured system whose characteristics are not readily apparent. In this case, the product of permeability and formation thickness is obtained, a very useful quantity for deliverability and well condition determination. In the case of the time matchpoint, frequently the porosity is not known, and, since the thickness also is not known, there is a dilemma as to the kind of useful calculation available from the time matchpoint. Fortunately, important and useful information can be obtained from the time matchpoint. The product of porosity, compressibility, and thickness can be computed. This product is sufficient to make an initial, preliminary estimate of the capacity of the system.

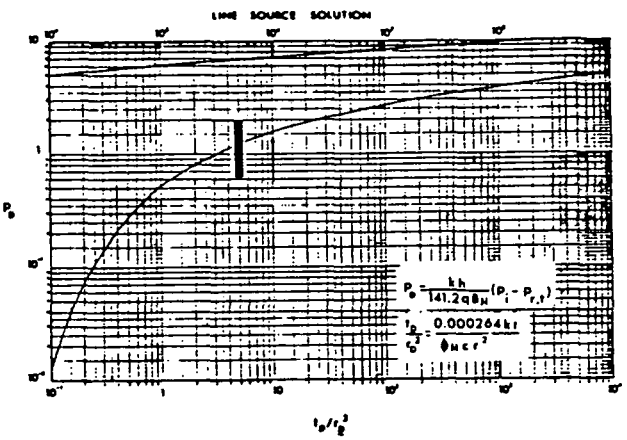


FIGURE 1 Continuous Line-Source Solution Type-Curve

The result obtained by this method is definitely preliminary, and should be checked by material-energy balance performance matching as production follows. Several uncertainties have been identified which render the results of the test uncertain. The Theis line source method depends on a single phase fluid flow model. There may be carbon diox-

ide or steam caps in geothermal systems. In this case, the compressibility of the system may be close to that of gas, rather than liquid. Another problem is that geothermal systems are often fractured systems. Recently, Deruyck (1980) studied interference testing in fractured (two-porosity) systems, and Kucuk (1980) has offered a similar study. It appears that this sort of system should be studied further.

Both show that two-porosity system interference results may resemble the Theis curve for a homogeneous system, but the parameters which result from type-curve matching can be uncertain.

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GEOTHERMAL WELL STIMULATION TREATMENTS

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The stimulation of geothermal wells presents some new and challenging problems. Formation temperatures in the 300-500°F range can be expected. The behavior of frac fluids and proppants at these temperatures in a hostile brine environment must be carefully evaluated before performance expectations can be determined. In order to avoid possible damage to the producing horizon of the formation, the high-temperature chemical compatibility between the in situ materials and the frac fluids, fluid additives, and proppants must be verified. Perhaps most significant of all, in geothermal wells the required techniques must be capable of bringing about the production of very large amounts of fluid. This necessity for high flow rates represents a significant departure from conventional oil field stimulation and demands the creation of fractures with very high flow conductivity or large fracture surface areas in the case of matrix permeability dominated formations.

Stimulation treatments have been conducted in formations which produce hot water as a result of both matrix permeability and from natural existing fracture systems. The following targets of opportunity are of particular interest:

- Wells that require additional drainage area because of insufficient formation permeability.
- Wells that did not intersect nearby major fracture systems.
- Wells that suffered man made damage during drilling or completion operations including mud or cement invasion.
- Wells that require periodic remedial treatment as a result of fluid production related damage.

Although numerous criteria have been established for the selection of candidate wells, the most significant is definite proof of a good producing reservoir. This data is normally obtained from offset well production.

Although sand is generally used as a proppant today and it has been the most widely used in the past, it is not strong enough to withstand the conditions in geothermal wells at elevated temperatures. Sand is definitely affected by temperature, particularly when tested in hot water or brine at various closure stresses. Figure 1 shows the effect of temperature on common frac sand (20/40 mesh). These results are short term results and only suggest the severity of long term field results.

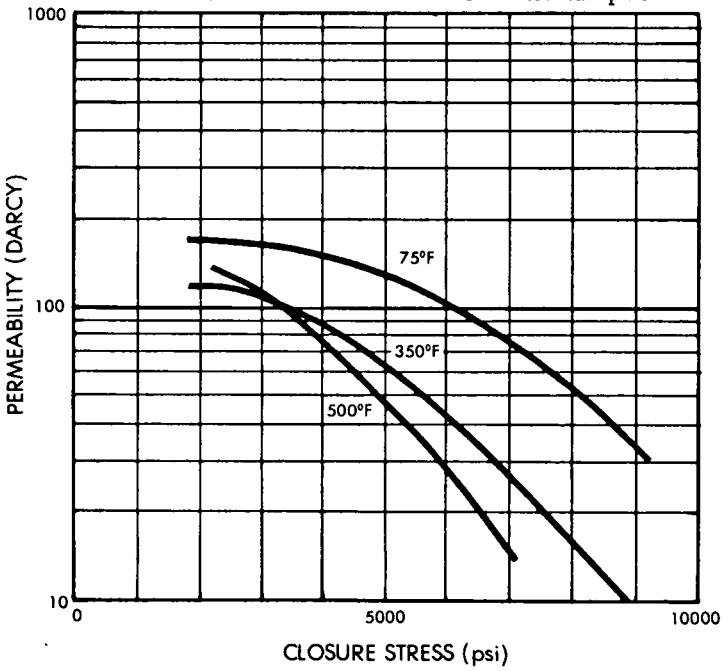


Figure 1. Temperature Effects on 20/40 Brady Texas Sand.

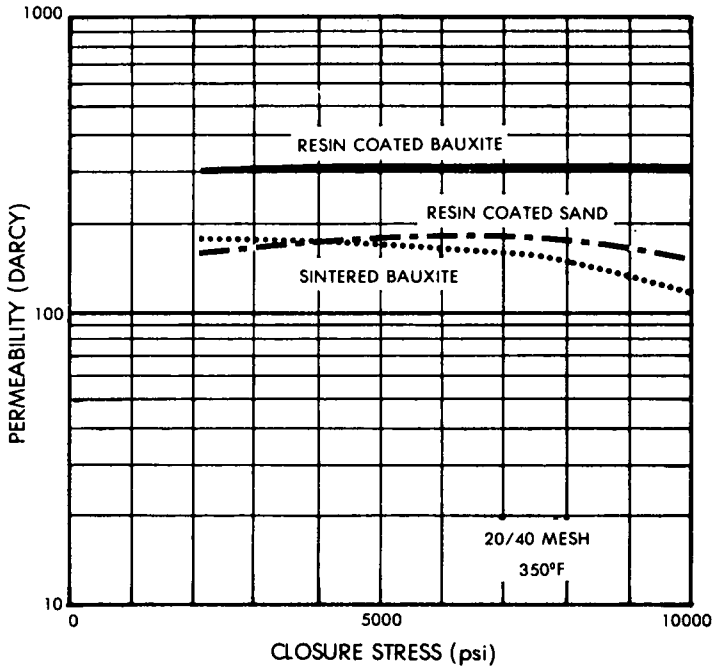


Figure 2. Permeability vs. Closure Stress for Temperature Insensitive Proppants.

There are several mechanisms that can destroy sand grains in the fracture. First, the sand is brittle and point-to-point loading can cause brittle failure. Second, sand is full of microfractures and faults which weaken the sand. Finally, when sand is stressed in a corrosive medium like hot water, stress corrosion cracking appears to destroy the sand at low closure stresses. High temperatures and high stresses combine to bring out the worst properties of sand.

The strongest proppant tested to date is Resin Coated Bauxite. It shows no temperature sensitivity or permeability decrease under load. The Resin Coated Sand is not temperature or load sensitive but does have a slightly lower permeability at any closure stress due to a slightly different distribution of particle sizes. Figure 2 shows the permeability of Resin Coated Bauxite and Resin Coated Sand under varying closure stress to 10,000 psi at 350°F. No temperature differences or sensitivities were found so tests at all temperatures gave the same results shown in Figure 2 within experimental scatter. One important point is that the resin coated materials are cohesive; therefore, once emplaced in the fracture flowback is reduced during production. Although slightly crushable, the Sintered Bauxite is much stronger than sand and effectively inert in hot brines. Figure 2 shows how Sintered Bauxite permeability behaves under increasing closure stress.

Under the Geothermal Reservoir Well Stimulation Program, two field experiments were performed at the Raft River KGRA in 1979. The first well stimulation experiment, performed on Well RRGP-4, used the "Kiel" dendritic fracturing process. A 200-foot vertical fracture was created at the wellbore. Post-stimulation production data indicate that Well RRGP-4 productivity was improved, but not to the hoped-for level of other wells in the field. The second well stimulation experiment, performed on Well RRGP-5, was a conventional massive hydraulic fracture treatment. A new vertical fracture of 140+ feet was created. Production tests suggested that the hydraulically created fracture intersected natural fractures very near the wellbore. Although the final well production rates were not as high as desired, the field experiments were technically successful in creating the artificial hydraulic fractures planned and have contributed significantly to the development of geothermal well stimulation technology.

The third and fourth field stimulation treatments under this program have just been completed in Republic Geothermal well 58-30 at East Mesa, CA. Preliminary flow test data indicates that the productivity was increased by a factor of 2.3 in the upper interval fracture stimulation treatment. The lower interval is currently being evaluated and the results from this treatment will be reported later.

GEOTHERMAL UTILIZATION TECHNOLOGY

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This paper describes geothermal energy utilization technologies as applied in electric power generation. Types of geothermal power plants are described, and some design considerations for their heat rejection and emissions abatement systems are indicated.

Commercial geothermal power plants utilize the two types of hydrothermal resources — vapor (steam) dominated and liquid (brine) dominated. Work on geopressured, hot dry rock, and magma resources is currently underway and could lead to commercialization of geopressured and hot dry rock resources in the 1990's. However, development of magma resources is expected to be long term.

Direct Steam Process. For vapor dominated resources, a direct steam process is used, as illustrated in Figure 1. In this process, steam from geothermal wells passes through particle separators into a turbine. The remainder of the process is similar to most other low-pressure steam power plants. The turbine exhaust is condensed by either a direct contact or a surface condenser, and the condensate is reinjected or used as cooling water makeup. Direct contact condensers are less expensive, but surface condensers are usually needed where hydrogen sulfide (H_2S) abatement is required. Commercial direct steam power plants are operating in the United States, Italy and Japan. Unit size for recent installations is usually about 50 MWe, with the largest being 135 MWe (net). In the U.S., capital cost for a direct steam power plant (not including field costs) is about $450/kWe, and total energy cost is less than with fossil fuels.

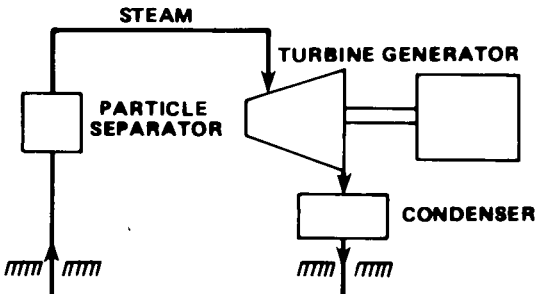


Figure 1 DIRECT STEAM PROCESS

Flashed Steam Process. Commercial power generation from liquid dominated resources uses a flashed steam process, as illustrated in Figure 2. Steam is generated by flashing brine in the wellbore, a flash tank/separator, or both depending on resource conditions. During the development of this process, the turbine, condenser, cooling tower, and balance of plant technologies were readily adapted from direct steam geothermal power plant processes and from low pressure fossil-fired steam plants. Commercial flashed steam plants of up to 50 MWe are operating in New Zealand, Japan, Mexico, El Salvador, and the Philippines. The first commercial scale flashed steam plant in the U.S., a 50 MWe

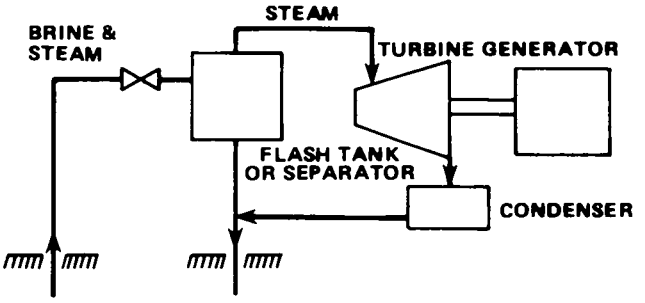


Figure 2 FLASHED STEAM PROCESS

unit, is to startup in 1982. Typical capital cost for these plants (excluding field) in the U.S. is about $750/kWe. Energy costs are less than for oil or gas and compete with coal.

The original flashed steam units used one flash stage, but some recent plants use two flash stages with steam supplied to the turbine at two different pressures. This uses the geothermal brine more efficiently, and requires fewer wells. Additional improvements can theoretically be accomplished by using three or more flash stages. However, two stages are usually the practical maximum because the gain in brine energy utilization does not normally offset the additional complexity and cost.

Processes Under Development. Power generation processes under development, but not yet commercial, include the binary cycle, and the two-phase expander.

A binary cycle is a closed Rankine cycle using a working fluid heated by hot geothermal brine, as shown in Figure 3. The working fluid is a halocarbon, a light hydrocarbon, or a mixture of light hydrocarbons. The main advantages of a binary cycle compared to a flashed steam process are that more energy can be recovered per unit mass of brine, lower temperature resources can be used, and no H_2S abatement system is needed since the H_2S never separates from the brine. The binary cycle is under development in Japan and the United States.

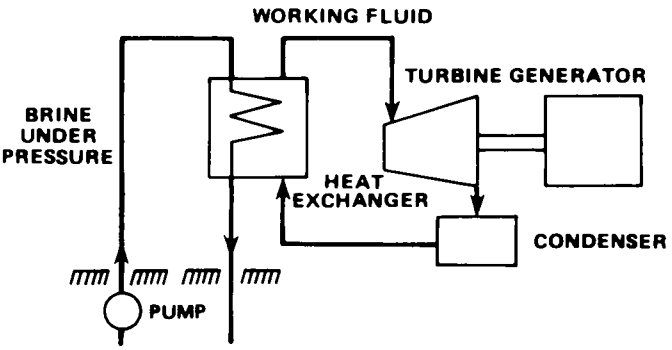


Figure 3 TYPICAL BINARY CYCLE

According to thermodynamic theory, the best brine utilization would occur when the two-phase flow from a liquid-dominated well is expanded through a specially designed two-phase expander to generate power. Two types of two-phase expander, the rotary separator and the helical screw, have been built in small size units (20 and 600 kWe respectively) and are undergoing tests at various liquid-dominated fields.

Heat Rejection. The following four systems to dissipate the power plant waste heat are the ones most often considered: wet cooling towers, dry cooling towers, wet/dry cooling towers, and air-cooled condensers. The principal selection criteria are the requirement for minimum electric energy cost and the availability of makeup water. Wet cooling towers are used at present, but the others may be utilized in the future, especially for some of the more arid resource locations.

Emissions Abatement. Since geothermal fluids from hydrothermal resources contain varying amounts of H_2S, abatement processes are often required for geothermal power plants. The approach in current designs is to treat the noncondensible gases downstream of the power plant using a Stretford unit to convert the H_2S to elemental sulfur. However, other processes are under development to remove the H_2S both downstream and upstream from the plant. If downstream H_2S removal in addition to that provided by the Stretford unit is required, secondary treatment to remove H_2S from the condensate must be applied. At present, oxidation with hydrogen peroxide is used for this purpose.

Conclusion. For steam and brine resources, cost competitive, commercially proven utilization technology is available. Much of it has years of service proof in other applications. The binary cycle for moderate temperature brine resources and the theoretically attractive two-phase expanders are still developmental.

RECENT FEDERAL GEOTHERMAL LEGISLATION

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This paper will briefly review recent federal legislation providing important new incentives for geothermal development. It will focus on two pieces of legislation - the Crude Oil Windfall Profits Tax Act and the Energy Security Act - enacted earlier this year, and will touch on geothermal leasing legislation pending in Congress as of this writing.

WINDFALL PROFITS ACT

The Windfall Profits Act (WPA) liberalizes certain tax credits first made available for geothermal and other alternative sources by the National Energy Act of 1978 (NEA),[1] but retains or imposes important limits on the availability of these credits.

The NEA provided two types of tax credit for geothermal investments, both of which are affected by the new WPA provisions. A "residential energy credit" is available for expenditures, including labor costs, for property which transmits or uses geothermal energy to provide heating, cooling or hot water for use in the taxpayer's principal residence. Under the NEA, the allowable credit was 30% of the first $2,000 of expenditures plus 20% of additional costs up to $10,000, for a total possible credit of $2,200. The WPA increases the residential credit to a flat 40% of expenditures up to $10,000 for a maximum credit of $4,000, and makes clear that the maximum credit is available separately for each unit of a cooperative or condominium development.

The NEA also established a "business energy investment credit" for certain "energy property" investments made by persons engaged in a trade or business. Among other things, such property includes most equipment employed to "produce, distribute or use" geothermal energy, as well as specified equipment (such as heat exchangers) used to increase energy efficiency in existing buildings. The NEA allowed a 10% credit for such investment; the WPA increases this to 15% and extends its availability through 1985. Under the NEA, "public utility property" - defined very broadly by the IRS - is ineligible for the credit. Despite the efforts of geothermal proponents, the WPA did not succeed in deleting this important exclusion.[2]

In computing expenditures for purposes of both the residential and business credit, the WPA now requires taxpayers to exclude any portion financed by any federal, state or local energy subsidy program and, as to the business credit, any portion paid with proceeds from tax-exempt industrial development bonds.

ENERGY SECURITY ACT

This act, known to many by its previous designation as S.932, establishes important new geothermal loan programs; expands and streamlines the federal Geothermal Loan Guarantee Program (GLGP); extends 1978 Public Utility Regulatory Policy Act (PURPA) benefits to geothermal small power producers; and mandates the first steps toward a federal reservoir insurance program.

Reservoir Confirmation Loans. The Act authorizes low-interest loans for

projects designed to explore for or determine the economic viability of geothermal reservoirs, consisting of surface exploration and exploratory drilling. Loans not exceeding $3 million may cover up to 50% of project costs, or 90% for projects intended to provide space heating or cooling or process heat in structures existing or under construction. These loans are repayable out of revenues, and may be forgiven if the reservoir turns out to be unacceptable for commercial development.

Feasibility and Construction Loans. The Act authorizes low-interest loans of up to 90% of the cost of feasibility studies and license applications, and up to 75% of the costs of construction, for direct applications by geothermal utility or industrial development districts, municipalities, cooperatives, non-profit organizations or Indian tribes. No dollar limit is specified. Feasibility study loans may be forgiven if the project is shown not to be technically or economically feasible.

GLGP Modifications. Prior to this Act, the GLGP was authorized to guarantee up to 75% of aggregate geothermal project costs. The Act increases the guarantee limit to 90% for municipalities and cooperatives (subject to certain exclusions for electric transmission lines). To remedy long administrative delays which have hindered the GLGP to date, it directs the Secretary of Energy to establish and implement procedures providing for a final decision on all loan guarantee applications within four months of filing. It also extends the termination date of the GLGP from 1984 to 1990.

PURPA Amendments. The Act clarifies the 1978 PURPA amendments to the Federal Power act to make geothermal electric producers eligible to apply for FERC interconnection and wheeling orders. Geothermal power producers of up to 80 MW capacity are also made eligible for the benefits of PURPA §210 rules requiring electric utilities to sell electricity to and buy it from small power producers, and exempting such producers from certain federal and state utility regulations.

Reservoir Insurance. Although earlier versions of this legislation provided for a full-scale reservoir insurance program, the Act as passed mandates only a study of the need for and feasibility of such a program in terms set forth in the Act, and requires that findings and recommendations be made to Congress within one year.

PENDING LEASING LEGISLATION

At this writing, legislation substantially amending the leasing provisions of the Geothermal Steam Act of 1970 is pending in both the Senate (S. 1388) and the House (H.R. 6080). These bills differ considerably, and will probably undergo additional changes before becoming law. As they now stand, both would increase federal acreage limits; narrow the Steam Act's KGRA definition to facilitate direct heat applications and to narrow or eliminate the "competitive interest" criterion for KGRA designation; authorize free use permits for non-electric, non-commercial uses; and require expedited processing of lease applications. The Senate bill would also reduce minimum royalties for non-electric applications and provide for phased leasing in some cases. The final shape of these bills remains to be seen, but both bear close watching.

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1. For a detailed summary of NEA geothermal provisions, see the author's "1978 National Energy Act Applications to Geothermal Development" (Earl Warren Legal Institute; November 1978).
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GEOTHERMAL MARKET DEVELOPMENT AND COMMERCIALIZATION PROGRAMS IN THE WESTERN STATES*

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Introduction The geothermal energy resources of the nation and of the western states exist at various stages of resource assessment, confirmation, development and commercialization. State governments and the U.S. Department of Energy are jointly engaged through cooperative agreements in planning, marketing and implementing the utilization of the better known geothermal resources for both electric and direct thermal applications. This paper describes the structure of participants and activities which has been designed and implemented to accelerate the commercialization of geothermal energy in the western states.

Background State Geothermal Commercialization Teams were established within appropriate state agencies in mid-1977 to collect and evaluate the existing data on geothermal resources and the prospective development of those resources. The New Mexico Energy Institute (for the states of AZ, CO, NM, NV and UT) and the Oregon Institute of Technology (for the states of ID, MT, OR, WA and WY), under operations research contracts, were engaged to evaluate the technological and economic feasibility of developing the resources and to project the aggregated quantities of geothermal energy on-line through the year 2020. The products of these joint activities were site-specific, statewide, and regionally-aggregated scenarios for the development of the geothermal resources. Similar projects were also conducted in California and Hawaii. In 1978, ten states of the southwest and mountain west were joined together to form the Rocky Mountain Basin and Range (RMB&R) Regional Hydrothermal Commercialization Program, under the direction of EG&G Idaho, Inc. The focus of the State Team activities was shifted from resource scenario development to commercialization planning. Commercialization planning was defined to emphasize the matching of available resources with prospective uses and users. Three classifications of plans were created to represent the state of knowledge and the phase of commercialization of various resource-user pairs. Actual products of the State Team planning activities have been not only the plans themselves, which provide more refined measures of the prospective, potential and existing utilization of geothermal energy, but also the use of the plans as effective marketing tools for educating and persuading prospective users on the benefits of geothermal energy. Starting in the summer of 1980, the thrust of the State Team projects has been advanced further into the commercialization field. The prime activity of each State Team now is market development. Market development encompasses the technology diffusion elements of education, persuasion and adoption. Each State Team has activated a marketing strategy, plan and program for working directly with commerce, industries, utilities and communities to promote and implement the use of geothermal energy. Their marketing efforts are supported by resource assessment and confirmation projects of the University of Utah Research Institute and the State Coupled Resource Assessment Teams, by engineering evaluations of EG&G Idaho, Inc., by the site-specific economic analyses of New Mexico Energy Institute and the Geo-Heat Utilization Center, and by the market assessment services of Western Energy Planners, Ltd.

State Commericalization Planning The State Commercialization Planning activities

during 1979-80 consisted of several principal tasks, as follows: (1) Geothermal Prospect Identification; (2) Energy and Economic Analyses; (3) Area Development Plans (ADPs); (4) Site Specific Development Analyses (SSDAs); (5) Time Phased Project Plans (TPPPs); (6) Institutional Analyses and Handbooks; (7) State Aggregations of Projected Energy On-Line; and (8) Outreach. The three plans - ADPs, SSDAs, and TPPPs - were directed at matching geothermal resources and uses/users along three levels of resource and use knowledge. ADPs were prepared for county-wide or multi-county areas, including all resource prospects - proven, potential and inferred - and allowing all prospective uses - residential, commercial, industrial and agricultural. The ADPs provided a systematic procedure for aggregating the prospective geothermal energy supply and demand over time for the multi-county areas and the entire state. SSDAs were performed for single resource sites and specific uses; they were directed at proven or potential resources, at applications considered economically proven or feasible, and for projects with a commercialization status defined by preliminary planning or an advanced interest by a public or private sector participant. The SSDAs provided stimulation and technical assistance for the advanced planning and economic development of specific resource sites matched with specific energy applications. TPPPs were developed for a selected number of developer/user identified geothermal resource applications; the applications were defined by a proven resource, an economic use, and a commercialization status of an advanced stage of planning or an actual project underway. Examples of the state commercialization planning achievements are numerous and are documented in several technical progress and topical reports by the State Teams and DOE.

Market Development and User Assistance Formalized market development and user assistance programs were initiated by the State Teams of the RMB&R Region during the summer of 1980. The programs are designed to transfer knowledge on geothermal resources, utilization technologies, economics, regulatory practices, finanacial incentives, locational criteria, and decision processes to a targeted set of prospective and action-oriented developers and users. The basic philosophy and hope is that an expansive marketing effort, dedicated to selected participants, will accelerate more rapidly the commercialization of geothermal energy. The basic strategy of the geothermal marketing consists of four key elements: (1) collaboration with state and local officials; (2) identification of goals; (3) selection of target participants; and (4) performance of market development and user assistance. Different approaches are applied for resource-user pairs that are already colocated and for those that are not colocated. In the former case, the State Teams pursue direct communications with specific industries, commerce, utilities and communities that have energy requirements that match the colocated geothermal resources. In the latter case, the State Teams work through state and local economic development agencies to reach the in-state industries that are planning to relocate or expand within the state and the out-of-state industries that are seeking new plant sites within their state. Energy costs, availability, convenience and quality often dictate the marketing efforts to the colocated users; whereas business locational criteria - raw materials, labor force, transportation, markets, living environment and institutional incentives - dominate the marketing practices to the non-colocated users. A number of successful marketing products in each state can be reported from the activities of the State Commercialization Teams and the several regional DOE contractors. The successes in 1980 provide a track record upon which the market development and user assistance program will be expanded in 1981. Indeed, it has been demonstrated that a strong marketing activity is an essential element of the total national geothermal commercialization program.

*This work was performed under contract to the U.S. Department of Energy.

DIRECT APPLICATION OVERVIEW

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Direct utilization of geothermal energy for space and process heating, for the most part, utilizes known technology. Basically, hot water is hot water whether from a boiler or from the earth. The utilization of geothermal energy requires only straightforward engineering progress rather than revolutionary advances and major scientific discoveries. The technology, reliability, economics and environmental acceptability have been demonstrated throughout the world.

Direct utilization of geothermal energy was probably practiced by early man for cooking and heating. Today, over 7000 megawatts thermal (MWt) are utilized in the world for space heating and cooling (space conditioning), agriculture and aquaculture production and for industrial processes. Of this figure, over 1200 MWt are used for space heating and cooling; approximately 5500 MWt for agriculture, aquaculture, and animal husbandry; and over 200 MWt for industrial processes.

Typically, the agriculture-related uses utilize the lowest temperatures, with values from 80-180°F (27-82°C) being typical. Use of wastewater has wide applications here. The amount and types of chemicals and dissolved gases, such as boron, arsenic and hydrogen sulfide, are a major problem for this use. Heat exchangers and proper venting of gases may be necessary in some cases to solve this problem. Space heating generally utilizes temperatures in the range of 150-212°F (66-100°C), with 100°F (38°C) being used in some marginal cases and heat pumps extending this range down to 55°F (13°C). Industrial processing typically requires the highest temperatures, using both steam and super-heated water. Temperatures up to 300°F (150°C) are normally desired; however, lower temperatures can be used in some cases, especially for drying of various agricultural products. Though there are relatively few examples of industrial processing use of geothermal energy, they represent a wide range of applications, from drying of wool, fish, earth and lumber to pulp and paper processing and chemical extraction.

Most of present-day developments involve large-scale projects, such as district heating (Iceland), greenhouse complexes (Hungary) or major industrial use (New Zealand). Heat exchangers are also becoming more efficient and better adapted to geothermal use, allowing the use of lower-temperature waters and highly saline fluids. Heat pumps are extending geothermal development into traditionally non-geothermal countries, such as France, Austria and Denmark, as well as the eastern U.S.

Space conditioning. The most famous space-heating project in the world is the Reykjavik municipal heating project, serving about 97 percent of the 113,000 people in the capital city of Iceland. At present, a total of 1.0×10^{10} gallons (3.8×10^{10} liters) of geothermal fluid are used annually to supply 16,000 homes with space heating. One field supplies water through two 14-inch and one 28-inch (35 and 70 cm) diameter pipeline over a 12-mile (19-km) distance. The entire system provides 1840 GWh per year or 420 MWt (including a fossil-fuel-fired peaking station).

An example of individual home space heating is in Klamath Falls, Oregon, where

over 400 wells are used for space heating, using waters from 100-230°F (38-110°C). The principal heat-extraction system is the closed-loop downhole heat exchanger utilizing city water in the loop. Larger examples of space heating in Klamath Falls include the Oregon Institute of Technology campus, where three wells up to 1800 feet (550 m) deep produce up to 450 gpm (28 I/s) of 192°F (89°C) water and heat approximately 500,000 ft^2 (46,000 m^2) of floor space. District heating projects are being planned or are under construction in Klamath Falls, Oregon; Boise, Idaho; and Susanville, California.

Agriculture and aquaculture. In Hungary, greenhouse heating is second only to the USSR, with over 13 million ft^2 (1.2 million m^2) being geothermally heated. Many of these greenhouses are built on rollers, so they can be pulled from their location by tractors, the ground cultivated with large equipment, and then the greenhouse returned to its location. In Japan, greenhouses cover about 157,000 ft^2 (14,600 m^2), where a variety of vegetables and flowers are grown. Raising poultry through the use of geothermal energy has been a very successful enterprise. Here, under-the-floor heating is utilized in sheds where 40,000 chickens are raised annually. Another successful business is breeding and raising carp and eels. Alligators and crocodiles are also raised in geothermal water. These reptiles are being bred purely for sightseeing purposes.

Excellent examples of greenhouse operation exist in the U.S., the largest being the Honey Lake Hydroponic Farms complex near Susanville, California. Cucumbers and tomatoes are grown in a hydroponic system. Channel catfish are raised by Fish Breeders of Idaho near Buhl, using geothermal water. Using 6000 gpm (380 I/s) of 90°F (32°C) water, approximately 500,000 lbs (230,000 kg) of fish are raised annually.

Industrial processes. An example of industrial processing is the use of geothermal steam for the Tasman Pulp and Paper Company in New Zealand. Here, 100-125 MW (18 tons/hr steam) of thermal energy are used for the lumber drying, black liquor evaporation, and pulp and paper drying.

In northern Iceland, a diatomaceous slurry is dredged from Lake Myvatn. This slurry is transported through a pipeline and held in storage ponds. The 80 percent moisture is then removed in large rotary-drum driers using high-temperature geothermal steam. The plant produces 27,000 tons (24,494 t) of diatomite filteraids per year, most of which are used in beer processing in Germany.

Two industrial-processing uses of geothermal energy are of note in the U.S.: Medo-Bel Creamery in Klamath Falls, where low-temperature fluid is used for pasteurizing milk, and Geothermal Food Processors at Brady Hot Springs, Nevada, where high-temperature fluid is used for dehydration of onions and other vegetables.

Economics. At present-day prices, the geothermal application will cost about the same or less than the corresponding annual fossil-fuel cost. Due to the expected escalation of fossil-fuel prices, the costs of the geothermal system will decline. Most geothermal direct-use systems will pay for themselves in 5-10 years from savings in conventional fuel.

The economics are greatly enhanced where cascading (multi-stage use) is considered. The Japanese optimize cascading where geothermal fluids are first used for electrical power production, then space heating, cooking and bathing (Otake). Low- and intermediate-temperature geothermal resources can also be used to meet the base load of an energy demand. Heat pumps and fossil fuel can then be used to meet the peak demands, thus conserving the resource and minimizing capital investments.

THE USE OF GEOTHERMAL ENERGY FOR BIOMASSED-BASED ETHANOL FUEL PRODUCTION

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Biomass-based ethanol fuel production converts a low-grade energy form such as surplus and waste farm products into a valuable, transportable liquid fuel. The ethanol generating process is energy intensive, requiring temperatures in excess of 100°C (212°F). The substitution of low-cost hydrothermal geothermal energy for more expensive conventional fuels is one way of reducing the energy costs of biomass-based ethanol production.

The suitability of a geothermal resource as the heat source for an ethanol facility depends upon the resource characteristics (temperature, flow and exploration status), availability of a local source of biomass feedstock, existence of a local market for the ethanol and by-products, and the institutional logistics associated with development of a given site.

Certain phases of biomass-based ethanol production require a relatively high-temperature heat source. During liquifaction, a temperature of about 93°C (200°F) must be maintained for 2-1/2 hours (SERI, 1980). Shorter liquifaction process times can be achieved at higher temperatures (K. W. Jones, written communication). The distillation process requires temperatures in excess of 100°C (212°F) to allow distillative separation of the ethanol and water. With these temperature requirements in mind, it is obvious that a fairly high-temperature geothermal resource is necessary to serve as the sole heat source for an ethanol production facility. A geothermal resource with a well-head temperature of 127°C (260°F) has the minimum thermal energy necessary to satisfy the complete needs of the ethanol production process (R. J. Schultz, verbal communication).

The amount of geothermal fluid required in an ethanol production facility depends upon the geothermal resource temperature, the volume of ethanol produced, and the energy required to convert the feedstock into ethanol. This conversion energy generally ranges from 40,000 to 70,000 BTU per gallon of ethanol and depends upon the efficiency of the plant design (Lund, 1979). Predicting the flow rate from a geothermal well is difficult since permeability and reservoir production characteristics are poorly understood for most geothermal systems. Fluid production rates depend upon the careful selection of a successful drill site, and can be influenced by well drilling and completion techniques. Thus for many systems, particularly those for which there is little or no drill-hole data, geothermal fluid flow estimates represent the largest unknown and risk-laden factor. Also, the relatively large flow rates required by large-scale ethanol facilities may necessitate drilling several production wells.

Another important factor that should be considered in site selection is the

level of knowledge for a particular geothermal system, or the exploration status. There are some geothermal systems that have been the site of relatively intensive exploration efforts, including drilling. Development of these sites will involve less risk since the chances of drilling a successful well are better than in a system for which no drill-hole data exist. Confirmation of resource production characteristics (temperature and flow) should take less time and money at a well-understood system.

In order for alcohol fuels to make a positive impact upon the nation's total energy budget, the consumption of petroleum in the ethanol generating process must be kept to a minimum. The energy consumed in transporting the biomass feedstock to the ethanol generating facility, and the energy used to transport the ethanol and any by-products to the market must be included in the overall energy budget. To reduce this energy consumption as much as possible, geothermal ethanol facilities should be co-located with nearby sources of biomass feedstock and with a nearby market for the ethanol and any by-products. Large-scale ethanol facilities cannot rely upon surplus or waste farm products whose cost and availability may vary. Crops grown specifically as feedstock will be needed by large operations. Supplies of surplus farm products may be sufficiently reliable for small-scale operations.

Prior to site selection, the institutional factors associated with the exploration and development of a given site must be carefully considered. These could include, but are not restricted to, land ownership, (federal, state or private), resource ownership, environmental considerations, and permitting. The availability of water may present a serious barrier to geothermal ethanol development in areas where water is in short supply. Large-scale ethanol facilities will need irrigation water for the feedstock crops in addition to geothermal fluids and processing water. It may be feasible in some cases to use the geothermal fluids as irrigation and process water.

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GEOTHERMAL ELECTRICAL PRODUCTION IN THE U.S. PROBLEMS AND FUTURE PERSPECTIVES

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At least 15 of the western states are known to have geothermal resources of sufficient temperature for electric power generation. Geothermal resources could account for as much as 20,000 MWe of electric generating capacity by the year 2000. The technology for producing electrical power from dry steam and from liquid-dominated hydrothermal systems has been demonstrated in many countries around the world beginning at Larderello, Italy, in 1904. Current world installed electrical power generating capacity is about 1900 MWe. The United States currently generates about 800 MWe from dry steam resources at The Geysers in northern California, which is the largest geothermal power installation in the world. The Geysers is estimated to have a total geothermal power capacity between 2000 and 4000 MWe. Pacific Gas and Electric is currently operating 14 units at The Geysers with one additional 110 MWe unit under construction and three units undergoing review by regulatory agencies. If they are approved it will increase their capacity to 1,248 MWe by 1983. Another 340 MWe of capacity is proposed by 3 other operators at The Geysers. These units are forecasted to come on line by 1985.

Active exploration is presently going on in the United States in more than twenty separate areas. Successful discoveries have been reported at several locations including the Imperial Valley, California, Valles Caldera, New Mexico, Roosevelt Hot Springs, Utah, Raft River, Idaho, Beowawe, and Dixie Valley, Nevada, Honey Lakes, California and Puna, Hawaii. Exploration activities and preliminary agreements indicate that approximately 300 MWe of generation capacity outside of The Geysers area could be on-line by 1985. A summary of these activities where preliminary agreements have been announced show the following: California - 181 MWe, Hawaii - 3 MWe, Idaho - 5 MWe, Nevada - 55 MWe, New Mexico - 50 MWe, and Utah - 20 MWe.

Table 1 lists the U.S. geothermal power projects which are currently operational or are being developed. Estimates indicate that total U.S. geothermal power generation capacity in 1985 will be between 2000 and 3000 MWe. This modest beginning represents an expected growth rate of 15% per year. In comparison, the expected growth rate for the total electrical generation capacity in the United States over the same period is 5.3% per year.

The U.S. Geological Survey has identified several geological regions outside of The Geysers with significant potential for high temperature geothermal resources. These regions are the Imperial Valley of California, the Cascade Mountains of Oregon and Washington, the Basin and Range of Nevada and Utah and the island chains of Hawaii and Alaska. Currently the major area of exploration is the Imperial Valley of California, just north of the successful geothermal power development at Cerro Prieto, Mexico. Four different geothermal fields have been discovered so far in the Imperial Valley: Niland, Brawley, Heber, and East Mesa. Estimates of the total geothermal capacity of the Imperial Valley for electric power production vary widely, ranging from 1500-20,000 MWe capacity.

Severe salinity problems have been encountered in the Niland field, where dissolved solids concentrations of more than 25% have been encountered. The temperature range of the geothermal reservoirs varies from 180°C in the Heber field up to 360°C in the Niland field. The major technical limitations to full scale geothermal development is availability and reliability of equipment and

materials to handle the generally hostile working fluids. The main uncertainity in designing wet-steam power plants is predicting and controlling scale formation. This affects every aspect of plant system design, from the production reservoir through the power plant and back to the rejection system. Recent engineering developments by Morrison-Knudsen Company and Magma Power Company are solving the scaling problems through creative use of crystallizers and reactor-clarifiers. The development of brine handling techniques has made possible the design of a reliable brine base geothermal power plant, which is opening the Imperial Valley to power production.

Existing geothermal power plants and plants currently in the design and construction stages are evidence that geothermal power is competitive with other conventional power plants. Table 2 lists the estimated 1980 installed power cost for conventional and geothermal power plants.

In the Western System Coordinating Council region, utilities are projecting an average annual compound growth rate of 5.1% in total load. To meet their projected demand, utilities expect additions of 60,400 MWe of capacity between 1980 and 1988 which would be a 57.4% increase over the present capacity of 105,142 MWe. Of this expected increase, coal-fired generating units account for 37.7%, nuclear facilities represents 31%, hydro accounts for 15.6% and oil-fired plants represent 9%. Three percent of the increase is forecasted to come from geothermal. Continued difficulty in licensing and constructing coal and nuclear facilities is increasing the need for an expanded contribution from geothermal. Geothermal power is not only a technically available future energy sources, it is rapidly becoming and economic necessity for supplying our future power needs.

Table 1: U.S. GEOTHERMAL PROJECTS

Location	Technology	Capacity	Starting	Sponsors
The Geysers, California	Natural steam cycle	800	1960-1980	Pacific G & E Co.; Union Oil Co. of CA
Heber, California	Binary cycle	45	1984	DOE; EPRI; San Diego G&E Co.; Chevron Resources Co.
East Mesa, CA	Binary cycle	11	1979	Magma Power Co.
Raft River, ID	Binary cycle	5	1980	DOE
Valles Caldera, New Mexico	Direct-flash steam cycle	50	1982	DOE; Public Serv. Co. of NM; Union Oil Co. of CA
Northern Nevada	Direct-flash steam cycle	50	1984	Sierra Pacific Power Co. and other utilities
Heber, California	Direct-flash steam cycle	41	1982	Southern CA. Edison Co.; Chevron Resources Co.
Roosevelt Hot Springs, Utah	Direct-flash steam cycle	20	1983	Utah Power & Light Co.; Phillips Petroleum Co.
Brawley, California	Direct-flash steam cycle	10	1980	Southern CA. Edison Co.; Union Oil Co. of CA

Table 2: NATIONAL AVERAGE - POWER PLANT CAPITAL COST*

Type	Cost per KW
Nuclear	$900-1500
Coal-Fired	$790-1100
Oil Fired	$700-800
Hydro	$425-780
Geysers Geothermal	$700
Imperial Valley Geothermal	$1200
Utah Geothermal	$1000

*1980 estimated installed cost

ENVIRONMENTAL ISSUES & CONCERNS IN DEVELOPMENT

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Geothermal resources have long been considered "clean" sources of energy. In many instances, the environmental impacts of geothermal development are minor when compared to other energy technologies. However, geothermal environmental concerns cannot be dismissed entirely.

Potential impacts include induced seismicity, land subsidence, degradation of air and water quality, interference with developed water resources, habitat destruction, changes in socioeconomic conditions, and the disturbance of cultural resources. The magnitude and importance of these impacts vary significantly with the geothermal resource, geographic location, and the type of development. Few of these potential impacts are unique to geothermal and most can be controlled or eliminated.

The four primary concerns for most large geothermal developments are impacts on air and water quality, induced seismicity, and subsidence. Of these, the most well known and researched are air quality impacts, including releases of hydrogen sulfide, particulates, and radon. Unabated releases of H_2S at The Geysers in California are 1.7 kg/kw-h. California standards were exceeded as much as 10% of the time in the development area in 1976[1]. PG&E is installing surface condenser and processing systems which could reduce these emissions by as much as 90%. The hydrogen sulfide of lower temperature hydrothermal resources is generally less than that encountered at The Geysers. The development of these resources for direct uses frequently includes closed-cycle systems. In these instances, air quality impacts are negligible.

Geothermal areas are commonly seismically active. Most of this natural activity occurs as microearthquakes and the frequency can range from a few events per year to several events per day. Geothermal development may result in an increase in this microseismic activity due to pressure changes or thermal stresses created by the production and injection of geothermal fluids. Induced seismicity is believed to have occurred at The Geysers, but the increased level of activity has not been found to be significant[2]. The risk of induced activity is low if injection pressures are kept below the fracture pressure of the reservoir, and if injection into existing faults is avoided.

Subsidence can result wherever large quantities of fluid are withdrawn from relatively unconsolidated sedimentary rocks. The environmental significance of subsidence is based on its magnitude and the sensitivity of surface developments to changes in elevation. Subsidence of as much as 8 m has been recorded as a result of groundwater withdrawal in the San Joaquin Valley and an average of 1.5 m of subsidence per year occurs at the Wairakei geothermal field in New Zealand[3]. Injection is the primary method of controlling subsidence.

The primary concern faced by most geothermal developers is the impact on water resources. The method of geothermal fluid disposal will determine the magnitude of water resource impacts. Disposal options include discharge to surface waters, evaporation, land applications, and injection. The option employed depends on the quality of the geothermal fluids, which ranges from drinking water quality to total dissolved solids an order of magnitude greater than sea water. Specific constituents in otherwise good quality fluids may result in disposal restrictions. This has occurred in Boise, Idaho, where geothermal fluids are low in total dissolved solids but high in fluoride (as high as 24 mg/l).

Injection is considered the most environmentally acceptable method of fluid disposal. While minimizing surface water contamination, injection may also reduce the risk of subsidence and may prolong the life of the resource by maintaining reservoir pressures. However, injection too close to the resource may result in "short-circuiting", while injection into other aquifers could lead to groundwater contamination.

Tests at the Raft River, Idaho, geothermal development have shown that there is significant vertical communication in fracture-controlled reservoirs. In such instances, injected fluids may migrate into aquifers developed for beneficial uses. This potential for migration and contamination of domestic aquifers is presently addressed in federal and state injection regulations and will affect the injection schemes of future geothermal developments.

In conclusion, disposal of geothermal fluids will be a major environmental factor in the development of geothermal resources. While air quality is the prime environmental concern at The Geysers, it will not be a concern for those developments utilizing closed-cycle systems. The potential for land subsidence and induced seismicity is difficult to predict, but these impacts can be controlled with carefully designed production and injection procedures.

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GEOTHERMAL FINANCING OPPORTUNITIES AND ACCOMPLISHMENTS

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A major financial commitment has been made for geothermal exploration and development by both the private and public sectors in the United States. Oil, gas and mineral companies have already instituted research and development programs for geothermal, and the recent mandate on alternate energy by the administration can only accelerate them. The recent passage of the synfuels bill, with its provisions for additional investment tax credit for qualifying geothermal equipment, in addition to previously enacted legislation has continued the trend of active Federal support for geothermal. Unlike oil and gas, however, geothermal is a site-specific resource and must be developed on a prospect basis. Since utilization and conversion therof, a customer for the energy produced is confronted by the possibility of losing its investment in the plant if the reservoir should fall. The major identified customers for this energy are the electric utilities. Since their capital bases have vastly different risk and rate of return criteria from the producer companies, an impasse appears to have developed as to how to bring about full-scale resource development and cash flow.

This paper suggest a financing tool by which this dilemma can be resolved and by which operating experience - the key to successful commercialization - can be accumulated as early as possible in the exploration and development process. Recently, however, two important developments - the commencement of operations at the Magmamax plant (11 MW) at East Mesa and the startup of the Southern California Edison 10 MW plant on Union Oil's Brawley property have suggested that a phased development strategy for new reservoirs may go a long way to mitigating perceived financial risks.

Since 1960, and until recently, the growth and prosperity of the geothermal industry has been severely limited by its narrow development base. One reservoir alone - The Geysers - is currently operated on a major commercial cash-flow-producing basis. Only recently has it finally become apparent that other reservoirs discovered during the last few years have been realistically targeted for startup dates for commercial production and cash flow generation with Brawley and East Mesa being the first of these. Under the present approach the commercialization, however, it appears that an elapsed time of eight to ten years, with continuing in-ground investments during that period, will be required from the date of initial discovery of a producing reservoir to the beginning of cash flow--the same lead time as may be expected for a coal or nuclear facility. One of the major factors causing this long lead time and startup delay is the absence of an accepted methodology and business approach to the financing of the initial commercial power generation facilities on a given reservoir. Such long lead time and unnecessary delays add significantly to the gross investment, and therefore cash flow required from the project.

The financing approaches to geothermal development projects must take into account the different risk and return requirements of the resource producer and energy end-user. In addition, risk to invested capital must be minimized and the economics of the overall project should be enhanced rather than diminished by the

financing package utilized. Clearly, the traditional borrower/lender relationship outlook will not serve in such an environment. What is needed here is the adaptation of proven project financing techniques into a specifically geothermal mold, utilizing to best advantage all of the basic elements present in a geothermal development and utilization program. Project financing can be defined as a project in which the lenders look solely to the economics, i.e., cash flow, of the project for the repayment of their loans. I will develop this theme in my oral presentation by addressing some relevant questions:

What comprises a geothermal power plant financing project? The question here is one of definition. Before the developer of a given resource can realize any cash flow return on his in-ground investment, a buyer must be found who will not only commit contractually for the long-term purchase of the resource produced but also will finance the construction of the power plant conversion facilities. Without a buyer willing to do both of these things - no commercial cash-flow-producing project can exist. Both the production and utilization phases of a geothermal development project are inextricably tied together on a site-specific basis.

Financing Options. The DOE Geothermal Loan Guarantee Program (GLGP) is the major government-supported source of financing to the geothermal industry outside of the array of tax-benefits recently enacted. This program allows for the financing of a variety of project structures with different timings - being in essence both a flexible and constructive format for private sector and government cooperation. In spite of the benefits it provides in reducing the reservoir risk component in financing projects and the opportunity for borrowers and lenders to establish normal industry working relationships, this program has its drawbacks for publicly-held companies, especially utilities.

Commercialization/Development Strategy. A successful geothermal commercialization plan must proceed in prudent stages with adequate safeguards taken to ensure the protection of invested capital and long-term operational viability. A vital safeguard is the need for an adequate working capital supply to avoid collapse of the project due to temporary cash shortfalls. Three other factors should be addressed in this context: technological risk, bonding capacity (associated with cost-overrun protection), and the need for accumulating operating experience.

missing

HAWAIIAN GEOTHERMAL RESOURCE ASSESSMENT AND APPLICATION

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The Hawaii Institute of Geophysics initially became involved with geothermal exploration and assessment research in 1972 as part of the Hawaii Geothermal Project. This work culminated in the citing of the successful geothermal well HGP-A in the Puna district of the island of Hawaii. More recently, a state-wide geothermal resource assessment program was begun in 1978 under the joint sponsorship of the U.S. Department of Energy's Western States Cooperative Direct Heat Resources Assessment Program and the Hawaii State Department of Planning and Economic Development. During the initial phase of this work approximately twenty areas throughout the state were identified as having some evidence of potential for either a high temperature or a low temperature resource (Thomas et al., 1979). Of this total, seven are located on Hawaii: Kilauea east rift, Kilauea southwest rift, Mauna Loa southwest rift, Hualalai west flank, Kawaihae Keaau, and Kohala; six are located on Maui: Haleakala east rift, Haleakala southwest rift, Haleakala northwest rift, Lahaina area, Ukumehame and Olowalu Canyons, and Honokawai; six are located on Oahu: Kaneohe-Waimanalo (Koolau caldera), Lualualei Valley (Waianae caldera), post-erosional cones of the Honolulu series of volcanics, Waianae northwest rift, Koolau northwest rift, and Waianae southeast rift; the only areas on Kauai which are felt to have any potential are those associated with the post-erosional Koloa volcanic series vents.

Subsequent efforts toward the evaluation of the geothermal potential of each of the areas identified have been directed toward field exploration and verification of the available data base compiled during the preliminary evaluation work. The field survey techniques which have been applied include geologic mapping, mercury and radon surveys, groundwater chemistry and temperature measurements, resistivity and self-potential surveys, time domain electromagnetics soundings, seismic ground noise monitoring, and gravity and magnetic surveys.

Assessment studies (exclusive of drilling) have been completed in two areas (Keaau and Lualualei Valley), and are presently underway in seven others (Kilauea east rift, Hualalai west flank, Kawaihae, Lahaina, Ukumehame-Olowalu Canyons, Haleakala northwest rift, and Haleakala southwest rift). On the basis of the work completed to date, the evaluation of each of these areas is as follows:

Lualualei Valley: the results of groundwater chemistry, mercury-radon surveys, and Schlumberger resistivity soundings all suggest that residual thermal acitvity may be present within the Waianae caldera. Temperature estimates of approximately 125°C have been made for the resource, however, slim-hole drilling will be required to determine the character of the resource;

Keaau: although groundwater geochemistry anomalies were observed in this area neither mercury-radon nor time domain electromagnetic data have provided any evidence for a thermal anomaly in this area. It is considered unlikely, therefore, that a thermal anomaly is present in this area;

Puna: In that a high temperature resource has been proven by the HGP-A geothermal well, survey efforts have been directed toward delineating the magnitude of the reservoir and toward refining exploration techniques to be applied elsewhere. Recently acquired TDEM and misé-a-la-massé data suggest that the reservoir associated

with the HGP-A geothermal well is at least two miles wide and is elongated to both the east and west along the strike of the rift;

Hualalai west flank: groundwater and soil mercury data suggest that a thermal anomaly is present in this area, the results of geophysical surveys, however, have been less positive. Although it is believed that at least a low temperature anomaly may be present, further surveys are necessary before this can be confirmed;

Kawaihae: groundwater chemistry and temperature data, mercury-radon data, resistivity and aeromagnetic data all indicate that an anomaly is present to the west of Kawaihae Bay. Although further surveys are presently underway, the evaluation of the results obtained to date is that a low level thermal anomaly may be associated with a recent prehistoric cinder cone located west of Kawaihae Bay;

Lahaina: although data from mercury-radon surveys suggest that an anomaly may be associated with the post-erosional vents in this area, groundwater chemistry is not substantially altered nor have data from geophysical surveys in this area indicated significant anomalies. More geophysical work will be conducted in this area, however, it is presently believed that the probability for finding a significant thermal source is slight;

Ukumehame-Olowalu Canyons: groundwater chemistry and temperature data, Schlumberger sounding data and self-potential data all indicate that a thermal anomaly is present within Ukumehame Canyon. The estimated subsurface temperature ranges from 60°C to in excess of 125°C. Further geophysical and geochemical surveys are presently underway in an effort to identify the source depth and the magnitude of the identified anomaly;

Haleakala northwest rift: soil mercury-radon data and groundwater chemistry data indicate that an anomalous area may be associated with the trace of the northwest rift zone, however, geophysical data have not been able to identify a significant anomaly in this area. Further geophysical and geochemical work is required before an assessment of this area can be made;

Haleakala southwest rift: only a few preliminary geophysical surveys have been conducted in this area, however, the results obtained to date suggest that a resistivity anomaly may be present near the southwest end of this rift system. These results are substantiated somewhat by the fact that a relatively recent (1790) eruption occurred in this same area. Although considerably more work is required here, it is believed that the probability of a thermal resource in this area is at least as high as anywhere else on Maui.

Potential Geothermal Energy Application in Hawaii

Over ninety percent of Hawaii's electrical energy is derived from petroleum; by mid-1981 approximately 70% of that petroleum will be imported from foreign sources. Thus it follows that the application of geothermal energy most critical to Hawaii's future is the generation of electrical power. The discovery of a 358°C reservoir by the HGP-A geothermal well on the island of Hawaii has proven that the temperatures required for electrical generation are available; the construction of a 3 MWE well-head generator which is presently underway is intended to demonstrate that this reservoir can provide a reliable and environmentally acceptable source of electrical power for Hawaii. The geothermal potential estimated for the Puna reservoir alone ranges from a few hundred to a few thousand megawatt centuries. Nonetheless development of electrical generation capacity beyond the limited power requirements of Hawaii island will be dependant largely upon three variables:

1) Development of cable technology that would permit transmission of electrical power from Hawaii to Oahu. To date high capacity electrical transmission cables have not been installed to depths equalling the 7000 ft Hawaii-Maui channel.

2) Relocation of energy intensive industry to a geothermal power site. Industries which are presently being considered for location in Hawaii include manganese nodule refining and aluminum smelting.

3) Discovery of a resource of sufficient quality to generate electricity on the islands to the north of Hawaii island. The 1790 eruption on the southwest rift of Haleakala lends strong evidence in support of a moderate to high temperature resource in this area; even though the probability of discovering a resource on the islands north of Maui becomes more remote with the greater age of these islands, sufficient data do not yet exist to rule out this possibility entirely. In addition, the generation of electricity through a binary process, or by cogeneration with biomass, may prove to be a valuable approach if no other alternatives are available.

Direct applications of geothermal energy in industrial and agricultural applications offer a second major area in which Hawaii's geothermal resources can replace fossil fuel use. The major existing industry in Hawaii where this may be applicable is sugar milling which requires very large amounts of low grade energy as process heat. Although this industry already produces all of its own energy requirements from the incineration of bagasse and cane waste, application of geothermal energy in drying bagasse and processing the cane syrup could allow for more efficient electrical generation from the cane waste and might permit the use of excess bagasse as biomass for ethanol production or as livestock feed. Other potential applications of geothermal heat include ethanol production, cattle feed pelletizing and processing, fruit processing and drying, resort/spa development, and a variety of other industrial heating and drying operations.

In all of the above direct applications the critical variable in the use of geothermal energy is the proximity of the resource to existing industry or the willingness of one or more industries to relocate near a known or potential resource. A recent study of the economic feasibility of using geothermal fluids in an existing mill by Puna Sugar Company found this application to be highly favorable economically, however the costs of transmitting the thermal fluids approximately 14 km from the source to the plant rendered the entire project much less encouraging. The feasibility of developing a geothermal industrial park has also come under study by Dillingham Corporation. The present concept calls for the co-location of several industries requiring varying grades of heat energy. The geothermal fluids would be applied in a cascaded fashion so that the needs of each user would be met primarily by waste heat rejected by former users. The industries studied for this concept were ethanol production, cattle feed milling and papaya processing.

Although both of the above studies considered the Kilauea east rift as the geothermal source, several other potential geothermal areas in Hawaii also have the existing agricultural and industrial infrastructure for direct use applications. The more probable areas for future development, if a resource can be proven are presently believed to be: the Kilauea southwest rift (sugar processing), Kawaihae (beef and cattle feed industry), Haleakala northwest and southwest rift systems (sugar and truck crop processing), Ukumehame and Olowalu Canyons (sugar processing and tourist/spa development), Lualualei Valley (industrial processing).

In summary, the resource assessment work that has been conducted in Hawaii during the last several years has yielded encouraging results in locations throughout the state. Considerably more effort; including, and especially, drilling, will be required however, before the tentatively identified resources can be seriously considered for exploitation. The economic feasibility of developing Hawaii's potential resources for electrical and direct applications is still under study and has yet to be proven, nonetheless, under the present world energy market conditions it is believed that the development of Hawaii's geothermal resources will become both a certainty and a necessity.

3 MWe WELLHEAD GENERATOR PROJECT

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A 3 MWe wellhead geothermal power plant is currently under construction near Kapoho in the Puna district on the Big Island (Hawaii). This plant is located about 25 miles southeast of Hilo.

The sponsors of this project are the U.S. Department of Energy, the State of Hawaii (DPED), County of Hawaii, the University of Hawaii, and Hawaii Electric Light Co. (HELCO). The sponsoring agencies established the HGP-A Development Group to implement the project. The HGP-A/DG selected the Research Corporation of the University of Hawaii (RCUH) as its agent to organize and manage the design, construction, operations and maintenance of the power plant.

RCUH solicited qualification proposals, and on September 14, 1978, RCUH signed a contract with Rogers Engineering Company, Inc., of San Francisco to provide the required engineering services for design, procurement and construction management of the power plant facilities. Rogers Engineering selected the Hilo firm of Hirai and Associates to provide the site and civil works design.

The objectives of this proof-of-feasibility project are to demonstrate that the geothermal resources on the Big Island can be harnessed for power generation, and that this activity can be accomplished in an environmentally acceptable manner. The power plant is intended to be operated for two years, which should provide ample time to prove the feasibility of the project, and also aid in characterizing the resource and estimating the capacity of the reservoir.

The stimulus for this project was provided by the Hawaii Geothermal Project, which successfully drilled the HGP-A well in 1976. The well was drilled to a depth of 6,450 feet. The well intercepted a number of producing zones in fractured volcanics. The maximum recorded well temperature was 358° C (676° F), which is one of the highest ever reported in the world.

While this wellhead power plant may be small, it incorporates all of the design features, including environmental controls, that would be required of a commercial-size plant.

HELCO will operate the power plant and purchase the power for distribution to its customers in the Puna district. The sale of power is expected to provide the project with income of $200,000 per year, which should be more than adequate to offset the costs of operation and maintenance.

The power plant is located adjacent to the HGP-A well on 4.1 acres of land which is situated along the rift zone on the eastern flanks of the Kilauea Volcano. Because of the possibility that a volcanic eruption may occur near the plant site, he power plant is built in portable, equipment modules which can be disconnected nd evacuated on lowboy trailers in an emergency.

The equipment modules include the turbine-generator package; the shell and tube surface condenser with two-stage steam jet ejecters for maintaining vacuum in the main condenser; the electric switch gear and motor controls which are housed in a trailer; and the control room, office and chemistry lab which are housed in another mobile trailer. The cross-flow, mechanical draft cooling tower is field erected, so cannot be considered portable.

As part of the plant "hardening", a reinforced concrete box was built around the wellhead. In the event of a lava flow, the concrete box would be filled with crushed cinder, which will serve as thermal insulation for the wellhead valves; and a reinforced concrete cover will be placed over the box to prevent the cinders from being displaced by lava.

During normal plant operations, the power plant will utilize an incinerator/absorber system for H_2S abatement. The noncondensable gas extracted from the geothermal steam is combustible, so the gas will be incinerated to convert the H_2S to SO_2. The hot flue gases will be quenched and the SO_2 will be absorbed in dilute caustic solution in the absorber.

The sodium sulfite liquor from the bottom of the absorber will be disposed of in percolation basins. The subsurface water in the area is warm and brakish, so the Department of Public Health has given permission to dispose of the plant waste water by percolation. For a large power plant it is expected that waste water disposal will be by reinjection wells because of the larger volumetric flow rates and longer duration of operations.

During plant upset conditions, the steam will be vented to atmosphere through a rock muffler after the steam has been treated with caustic solution which is sprayed into the steam line, equipped with static inline mixers to increase the efficiency of reaction between the caustic and H_2S. The caustic injection and rock muffler systems were installed in December 1979 for noise and H_2S abatement during well flow testing. Limitation on noise was 65 dB_A maximum at one-half mile distance from the well site. The rock muffler reduced the noise level to 44 dB_A at the property line at the well site. The limit on H_2S discharge was 44 ppm. The overall emission rate during the test was less than 25 ppm.

Construction of the power plant facilities is expected to be completed by the first quarter of 1981. Total cost of the project is estimated to be $8,871,000. Major cost items include:

Well Workover (Repair)	$ 990,000
Well Flow Test Equipment, H_2S Abatement Chemicals, O & M	387,000
Power Pland Equipment	2,159,000
Phase I and II Construction	2,790,000
Visitors Center and Other Costs	351,000
Engineering Services for Drilling, Testing, Environmental Study, Plant Design and Construction Management	2,194,000
	$8,871,000

SUMMARY OF WELL TEST AND RESERVOIR ENGINEERING RESULTS FOR HGP-A

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The experimental geothermal well, HGP-A, drilled under the auspices of the Hawaii Geothermal Project, is located on the island of Hawaii in the southeast rift zone of Kilauea volcano. Drilling was completed to a depth of 6450 feet in April 1976 with 9-5/8 inch diameter production casing to 2200 feet and 7-5/8 inch diameter slotted liner to bottomhole. Cuttings and core samples obtained during drilling indicate that the region is composed of volcanic basalt with a profile that contains open fracture zones separated by relatively impermeable layers. The maximum bottom temperature during quiescent periods has been measured at 358°C. Test water samples were taken at surface at various times and under differing flow conditions, along with downhole water samples taken during static conditions. The median values for the downhole samples are shown in Table 1. As these figures indicate, HGP-A's effluent contains about 5 percent ocean water and has a fairly high silica content.

TABLE 1. HGP-A Geochemical Summary

pH	Less than 5
Elec. Cond.	3100 umho/cm
Salinity	2.3°/oo
Chloride	9.25 mg/l
Silica as SiO_2	420 mg/l
Sulfide	100 mg/l
Sodium	600 mg/l
Potassium	123 mg/l
Calcium	40 mg/l
Magnesium	1 mg/l
Tritium	At least 12 yrs. old

The well was initially flashed on July 2, 1976. The well testing program which followed included four long-term production flow tests during November and December of 1976, and January and March of 1977. Comparison of flow characteristics during the early stages of these production flow tests (Table 2) shows that with each subsequent test, the flow rate has increased. A possible explanation is that skin damage from drilling mud is being removed as each flow test partially cleans out embedded mud.

TABLE 2. Comparison of Discharge Tests at 25 Hours after Initiation of Flow

	Nov.	Dec.	Jan.	Mar.
Wellhead Pressure (psig)	47	53	59	59
Wellhead Temperature (°C)	146	150	151	153
Mass Flow Rate (Klb/hr)	87.9	103.4	114.3	120.4
Water Flow Rate (Klb/hr)	24	34	36	38
Steam Flow Rate (Klb/hr)	63.8	70.0	78.0	82.7
Steam Quality (%)	73	68	68	69
Enthalpy (BTU/lb)	888	833	845	842

Temperature and pressure profiles taken during the throttled flow tests in January are shown in Figs. 1 and 2. These profiles indicate that the fluid in the wellbore is a saturated mixture of liquid and vapor, and that flashing is occurring in the formation. Also shown in Fig. 1 is the temperature profile 25 days after the well was shut in (zero flow rate). Examination of Fig. 2 shows that the pressure profiles are essentially three constant slope lines meeting at the junction of the casing and slotted liner (2200 feet) and at approximately 4300 feet. These constant pressure gradient lines indicate that the major production zones are near bottomhole and in the vicinity of 4300 feet.

Some additional though limited information about the reservoir can be gained by interpreting actual measurements taken at HGP-A with standard petroleum engineering theories. (Cautious use of the results of these analyses is advised, since these techniques assume a single-phase flow, and the flow in HGP-A is two-phase). Following the December discharge, a pressure buildup test was conducted. Bottomhole pressure was measured using two Kuster KPG pressure elements and recorders in tandem to ensure that pressure data was acquired in spite of possible equipment malfunction because of the extremely high temperature. These measurements were the basis for determining two distinct wellbore storage effects. The product of permeability and production zone thickness (kh) was calculated to be approximately 880 millidarcy-feet, with the ressure drop across the mud-damaged skin of the well being 560 psi.

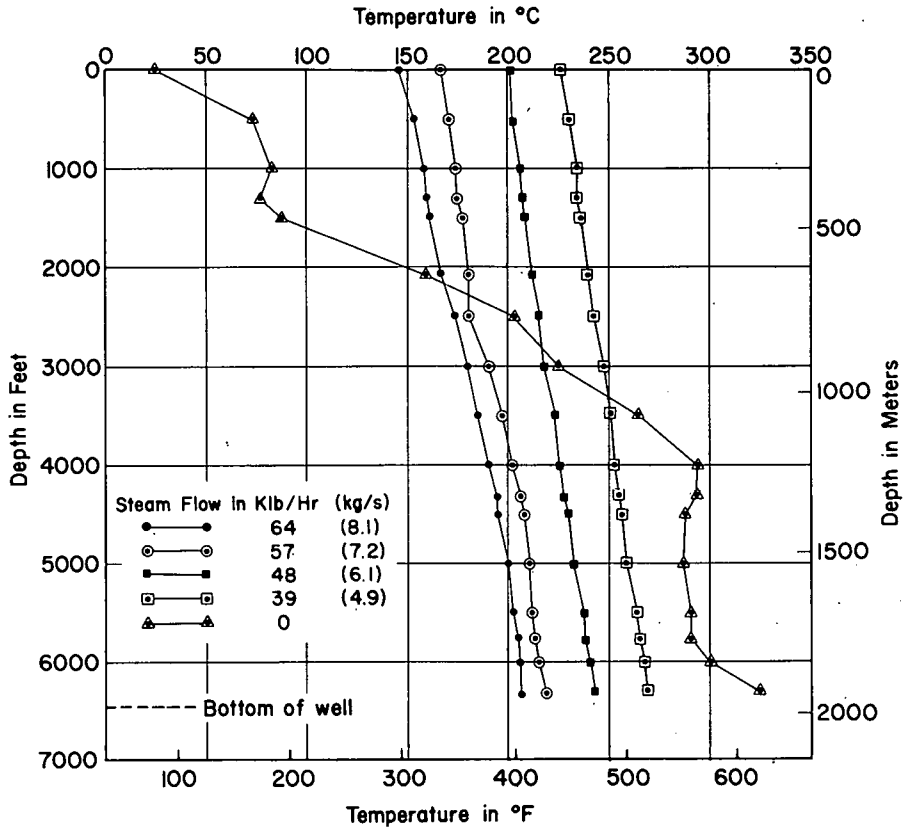


Figure 1. Temperature Profiles for HGP-A

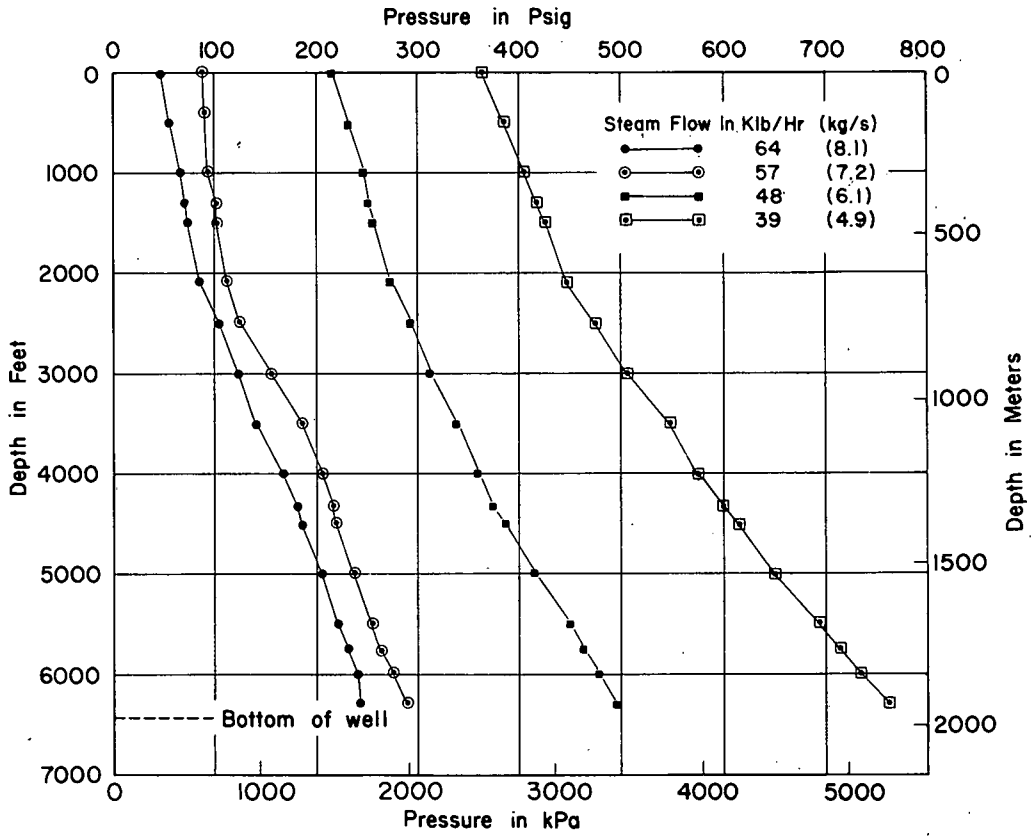


Figure 2. Pressure Profiles for HGP-A

Bottomhole pressure measurements made after HGP-A was shut in produced data which revealed at least two different production layers in the wellbore with differing kh values. The results of these analyses revealed a kh in the 1000-1500 md-ft range.

A summary of the results of tests to date is presented in Table 3.

TABLE 3. Summary of Preliminary Test Results and Analyses

Kapoho Geothermal Reservoir	HGP-A Geothermal Well
1. Liquid-dominated	1. During Flash, Borehole Contains Steam and Water at Saturation
2. Tight Formation: Permeability Thickness ~1000 md-ft	2. Flashing Occurs in Formation
3. Very High Temperatures ~350°C	3. High Wellhead Pressures ~160 psi at 50 Klb/hr Steam
4. Slightly Brackish Water	4. Producing Regions Probably at Bottomhole and 4300 Feet
5. Potentially Large Reservoir	5. Probably Has Severe Skin Damage
6. High Silica Content	6. Potential Power Output ~3.5 MWe
	7. Flows Have Increased with Each Test

In late 1979, the HGP-A well was reworked because of an apparent deterioration of the casing cement bond. The production casing length was increased to 3000 feet, its diameter was reduced to that of the slotted liner, and it was connected to the slotted liner which extends to bottomhole.

As part of the final power plant facility (to be completed in March 1981), the steam separator and associated flow meters and controllers for steam and brine flows were erected early so they could be used for a production flow test (January 1980). Hydrogen sulfide scrubbing equipment was also installed. This system permitted a comparison to be made of these results with those obtained previously. The flow test verified earlier throttled flow tests and finalized the design for the power plant. Other important benefits also resulted from the test: (1) operating personnel were trained; (2) test facility problems were resolved before the power plant is installed; and (3) the community realized that the facility was designed to operate in an environmentally acceptable manner.

U.S. DIRECT USE DEMONSTRATION PROJECTS

Edward G. DiBello
EG&G Idaho, Inc.
Idaho Falls, Idaho, U.S.A.

The application of hydrothermal energy for direct use by the private sector in the United States has been quite limited to date. The reasons most commonly given for the limited development of this alternative energy source are the lack of: (a) inexpensive and reliable exploration and drilling techniques, (b) knowledge of the resource base, (c) established geothermal laws and regulations, and (d) technical and economic data. Therefore, baseline information regarding direct applications is needed to assist prospective users in defining the engineering and economic requirements of direct use projects.

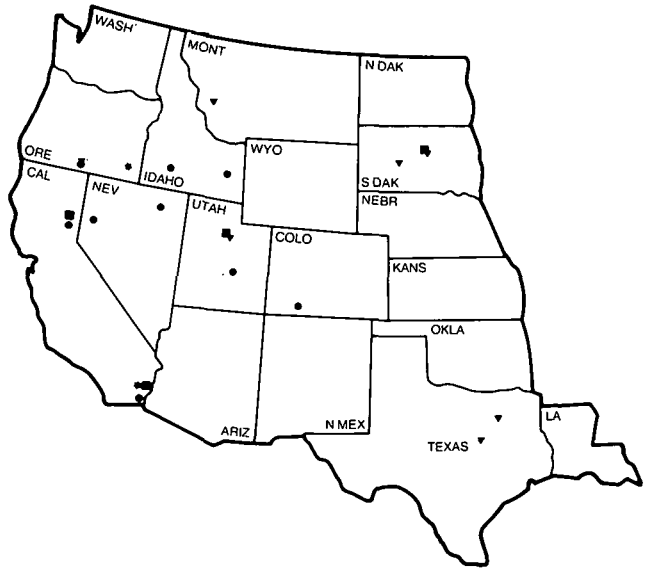
To stimulate development and build the necessary data base, the U.S. Department of Energy, Division of Geothermal Energy, in 1977 and 1978 issued two Program Opportunity Notices for cost-shared direct use projects, and 22 projects (Figure 1) were initiated as a result.

Each project is managed by a principal investigator who is assisted by a private-sector technical team. A flow diagram of a typical project is shown in Figure 2.

Environmental and institutional issues have been studied for all projects. To date, no project has been terminated due to unresolvable environmental or institutional constraints.

Thirty-three wells will be completed by 1981 under the auspices of this program, representing a total of 85,788 ft (26,148 m) drilled. The average production well depth for 20 projects is 2378 ft (725 m). Five projects, as presently planned, will use injection wells for disposal with an average depth of 2683 ft (818 m).

Figure 1 - Direct Use Projects



Industrial Process Sites
- ORE-IDA — Ontario, Oregon
- Holly Sugar — Brawley, California

Agribusiness
- Utah Roses — Sandy, Utah
- Diamond Ring Ranch — South Dakota
- Aquafarms International — Mecca, California
- Kelly Hot Springs — California

District Heating Systems
- Monroe City, Utah
- Klamath Falls, Oregon
- Boise, Idaho
- Elko, Nevada
- Madison County, Idaho
- Reno, Nevada
- Pagosa Springs, Colorado
- Susanville, California
- El Centro, California

Institutional Heating Systems
- Navarro College & Hospital Corsicana, Texas
- Warm Springs Hospital, Montana
- Utah State Prison, Utah
- THS Hospital, Marlin, Texas
- St. Mary's Hospital, Pierre, South Dakota
- Philip School, South Dakota
- Klamath Falls YMCA, Oregon

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Figure 2 - Project Flowchart

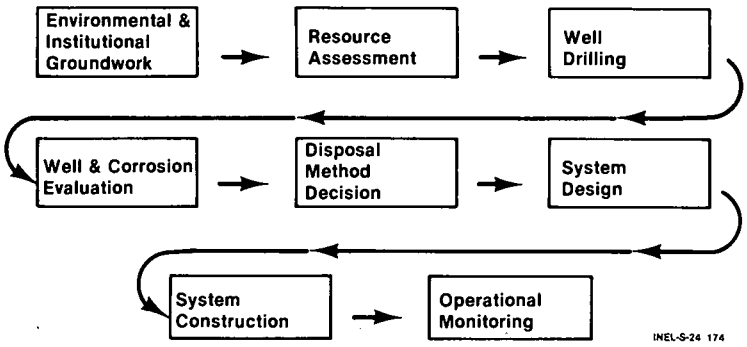


Figure 3 shows a simplified design for a typical direct heat application, whether district heating or industrial processing. All projects use existing technology and commercially available hardware in each of the processes. Several projects are already on-line (Klamath Falls YMCA and Diamond Ring Ranch) and others (Philip School and St. Mary's Hospital) are nearing completion.

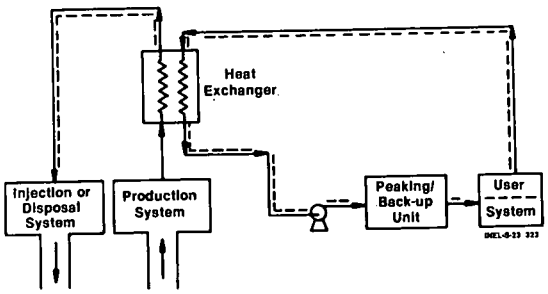
If all projects come on-line, the estimated energy replaced by the hydrothermal resource will be 1484.6 x 10^9 Btu/yr (49.6 MW-Yr). Assuming 100% conversion efficiency, this is equivalent to 2.66 x 10^5 barrels of crude oil per year. The projects and resultant energy delivered costs vary from project to project, as would be expected, due to the site-specific nature of hydrothermal development. Costs of some projects are summarized in Table I.

TABLE I - ENERGY COSTS

PROJECT	$/MBTU	$/INSTALLED KW
Pagosa Springs	4.97	134
Elko Heat	7.03	446
Diamond Ring Ranch	8.65	410
St. Mary's Hospital	9.07	441

As a result of these and similar projects, institutional barriers are being tested, private firms and organizations are gaining experience, and public awareness of hydrothermal energy is being increased. In addition, valuable environmental, technical, operational, and economic data are being generated. This information will be available in final reports to be issued upon project completion. The Department of Energy is also preparing a generic analysis on the overall program that will be available to those interested in hydrothermal direct use development.

Figure 3 - Direct Use System



Reference

Geothermal Direct Heat Applications Program Summary, Semi-Annual Review Meeting, El Centro, California, April 1980.

SECTION 9

SMALL SCALE HYDRO

SMALL SCALE HYDRO

Program Chairman: *David C. Willer,* Tudor Engineering
DOE Advisor: *Farwell Smith*
Overview Presentation: Thursday, December 11, 1:30 P.M.

"The National Hydropower Study" 2-110
Richard J. McDonald, Institute for Water Resources

SESSION I: Thursday A.M.

"Hydroelectric Assessments by Water and Power Resources Service" 9-1
Nelson J. Jacobs, Water and Power Resources Service
"The Hydroelectric Program at the Electric Power Research Institute" 9-3
Antonio Ferreira and Thomas R. Schneider, Electric Power Research Institute
"Recent Federal Legislation to Promote Small Scale Hydroelectric Projects" 9-5
Peter W. Brown, Energy Law Institute
"Small Scale Hydroelectric Development and the Environment: Issues, Challenge, and Opportunity" 9-8
Stephen G. Hildebrand, Oak Ridge National Laboratory
"State Legislative Issues in Small-Scale Hydropower" 9-10
Kenneth A. Wonstolen, National Conference of State Legislatures
"Hydropower and the Developer" 9-12
Al E. Hymer and Brent F. Russell, Idaho National Engineering Laboratory

SESSION II: Thursday P.M.

"DOE Demonstration Projects and Engineering Development" 9-15
W. W. Hickman, EG&G Idaho, Inc.
"Bulb Turbine Installation for Idaho Falls" 9-17
Jeffery Paine, City of Idaho Falls Electric Department
"Small Scale Hydro Plant at an Existing Dam: The Goodyear Lake Generation Station" 9-19
F. W. E. Stapenhorst, Pointe-Claire, Quebec, Canada
"Small Scale Hydro Development in Alaska" 9-21
Eric P. Yould, Alaska Power Authority

PRE

HYDROELECTRIC ASSESSMENTS BY WATER AND POWER RESOURCES SERVICE

Nelson J. Jacobs
Water and Power Resources Service
Denver, Colorado, U.S.A.

The Water and Power Resources Service (formerly Bureau of Reclamation) of the U.S. Department of Interior has a long, successful history of hydroelectric power development in the Western United States. The agency owns and operates 50-hydroelectric powerplants with a total installed capacity of 11,000 MW. In an effort to be responsive to current National goals of development of renewable energy resources, the Service has recently undertaken special studies to assess the potential for additional hydroelectric power development by the agency - primarily development of hydroelectric potential at existing Service water resource development projects. As a result of the agency's on-going planning program and one of these assessments, the Western Energy Expansion Study, the Service is presently actively studying development of 33 potential hydroelectric and pumped storage sites.

In addition, another assessment, the Low-Head Hydroelectric Evaluation and Inventory, is in progress with the first two phases being complete. Phase I was completed in-house by the Service and concentrated on identifying potential small hydroelectric development at existing Service project facilities; dams, diversion dams and irrigation canal drops. The report for this phase, "Assessment of Small Hydroelectric Development at Existing Facilities", was completed in July 1980. The study used an iterative process of analysis and screening to evaluate 159 potential small hydroelectric developments. A final screening resulted in identification of 37 sites which are considered economically feasible, would not result in significant environomental and social impacts, and would be acceptable to and supported by the affected publics. An additional 9 sites were concluded to be economically feasible; however, additional studies are required to quantify potential environmental and social problems that could result from their development.

Power and energy analyses were made using flow-duration techniques based on historical project flow data. Cost data used were based on the latest cost information from the industry and reflect cost savings based on projected standardization of small hydroelectric equipment and the other simplifying design assumptions. Benefit evaluations used in economic analyses were based on Water Resources Council procedures using a marketability approach based on the marginal cost of alternative power and energy sources. Capacity value was recognized as a firm energy value when dependable generation coincided with system power demand; either on an annual basis or seasonal peak-load basis. The selected plant size was based on an optimization of the net annual benefit from the projected development.

Phase II of the Low-Head Hydroelectric Evaluation and Inventory was a more general inventory of low-head hydroelectric development sites in the 17 Western States. This phase of the study was conducted by Tudor Engineering Company, under contract with the Service. Low-head is defined for the study, as those sites with hydraulic head of 20 meters (approximately 66 feet) or less. This phase of the study was divided into three primary activities. The national listing of hydro-

electric sites assembled by the U.S. Corps of Engineers as part of the National Hydropower Study was used as the original data base for the first activity. All sites except those in the 17 Western States were eliminated from the listing, as were all existing dams exceeding 20 meters of head. All identified potential sites exceeding 20 meters of head were removed from the listing and reentered into the listing as potential developments with less than 20 meters of head. Finally all sites with a potential capacity of less than 1,000 KW were eliminated.

For the second activity, an environmental data base for each of the states in the study area was assembled and the sites resulting from the first activity were environmentally screened to identify all sites with known serious environmental and social constraints.

For the third activity, 500 additional low-head hydroelectric sites were identified, environmentally screened, and added to the list resulting from the first two activities.

The report for this phase of the study was completed in August 1980 and contains a list of over 2,600 sites that have potential as low-head hydroelectric development sites. The final list also notes the degree, if any, of environmental constraints affecting the site.

From this gross list of sites, the Service selected 100 sites which appear to hold potential for economically feasible and acceptable development by the Service. The contractor is now performing appraisal-level evaluations of those 100 sites as Phase III of the study.

Potentially, the studies described could result in significant development of conventional hydroelectric and pumped storage capability by the Service for serving loads in the 17 Western States through use of renewable resources.

PRE

THE HYDROELECTRIC PROGRAM AT THE ELECTRIC POWER RESEARCH INSTITUTE

Antonio Ferreria* and Thomas R. Schneider
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Hydroelectric power is the dominant renewable resource in use today throughout the world. Its importance as a resource will continue in the future although its potential is limited by the availability of suitable sites.

Hydroelectric generation accounts for 10% to 13% of electric energy generated in the United States. As alternative energy resource cost soar, the value of this resource and utility interest in reconditioning and rehabilitating old plants and in building new plants have correspondingly and substantially increased. This renewed utility interest and cognizance of the necessity to reduce capital and O&M costs is surfacing many design, engineering, construction, operation and maintenance problems which are best resolved on an industry coordinated basis.

Of the existing 1,426 U. S. hydroelectric installation identified by FERC, the average size is approximately 40MW. In this context, the nomenclature of "small hydro" is a misnomer as it implies a minor class of little importance. The fact is that hydroelectric resource is widely distributed and a significant portion of the sites are of modest size.

The hydroelectric research program now being established at the Electric Power Research Institute will be directed at the full range of installation sizes. Further, this program is being established to provide a central resource for technology improvements and to assist the many utilities throughout the country now working to fully utilize the hydroelectric resource.

Results from the first project initiated is now available. A simplified analytical procedure has been developed to provide utilities with a rapid and reliable first level screening methodology. These analytical procedures can be used to assess the economic and engineering potential at a site with sufficient confidence so as to categorize the site as meriting further detailed assessment, being placed in a contingency status or dismissed.

As an additional step toward developing its hydroelectric research program the Electric Power Research Institute staff, supplemented by consulting services, has initiated a program of identification, prioritization and development of projects and studies to address the following types of generic research, development and demonstration objectives: (1) advance the state-of-the-art of hydroelectric technology, including the extrapolation of pump/turbine technology to higher heads, larger unit sizes with regulating ability; (2) improve the performance, reliability, and the availability of existing and new generating units; (3) improve the safety and reliability of existing and new dams and other water impounding and transfer structures; (4) reduce capital, operating, and maintenance costs of hydroelectric facilities; (5) assess, evaluate, and improve utilization of hydroelectric resources

*On assignment to the Electric Power Research Institute from Northeast Utilities.

and increase public and environmental acceptability of hydroelectric facilities.

The broad objectives will be addressed by selected projects and studies dependent on and determined by evaluation and availability of appropriate contract teams and the identified relative priorities and benefits to the industry. The procedures and methodologies will include the use of standard and straightforward design and engineering analyses as well as development of new computer-aided techniques and hydraulic model studies, a simplified methodology for economic screening and increasing plant efficiencies.

With increasing pressure on utilities, investor owned, rural electric and public, the need to research and review the hydroelectric potential of existing dams and new sites, both small and large, has increased. Hydroelectric is now an important energy resource and its continued development responds to the need to bring into service all types of electric energy generation which can compete technically, economically and environmentally with the existing fossil fueled sources.

PRE

RECENT FEDERAL LEGISLATION TO PROMOTE SMALL SCALE HYDROELECTRIC PROJECTS

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In the last two years, small scale hydroelectric technology has, through new federal initiatives, found a place in the "sun" of renewable energy technology. This paper will discuss in some detail the various provisions of the Public Utility Regulatory Policies Act of 1978 (PURPA), the Crude Oil Windfall Profits Tax Act of 1980 (COWPTA), and the Energy Security Act of 1980. These major pieces of energy legislation contain important provisions which attempt and do in fact create incentives for small scale hydroelectric development in the United States. These pieces of legislation, in a variety of ways, attempt to deal with three basic obstacles to the development of small scale hydroelectric power. These obstacles are or were a cumbersome, expensive and protracted licensing process at the federal level, an imbalance in the market power between small scale hydroelectric developers and integrated electric utility systems and consequent difficulties in marketing the product of hydroelectric facilities, and a lack of financing incentive compounded by the capital intensive nature of small scale hydroelectric investments. This paper will duscuss each of the provisions of the above cited legislation, cite the experience of the states and hydroelectric developers with such legislation and analyze implications of such legislation to hydroelectric development.

I. THE LICENSING PROCESS - THE FEDERAL LEGISLATIVE RESPONSE

With certain notable exceptions, such as the development of small scale hydroelectric projects in the Hawaiian islands, all small scale hydroelectric facilities which are connected with integrated electric utility systems are required to obtain a federal license from the Federal Energy Regulatory Commission (FERC) under the terms and conditions of the old Federal Power Act. Until recently, the process of obtaining a license for hydroelectric projects from FERC was protracted, cumbersome and expensive. More recently, FERC has made significant strides in expediting this licensing process and making its regulations simpler and understandable. However, there remains the problem under present law of the contested license application, or contested permit application which is also a cumbersome, protracted, and expensive process. Title IV of the Public Utility Regulatory Policies Act and Section 213 of Title II of the Public Utility Regulatory Policies Act and Section 408 of the Energy Security Act of 1980 all address the problem of delay and expense in the licensing process within the Federal Energy Regulatory Commission. Firstly, Title IV of the Public Utility Regulatory Policies Act exhorts and commands FERC to develop expediting licensing procedures for small scale hydroelectric projects of 15 megawatts or less located at existing sites. Happily, FERC has gone beyond the mandate in Title IV of PURPA and has developed a series of regulatory changes which considerably expedite the licensing process for minor projects of 1.5 megawatts or less and major projects at existing dams. Secondly, Title IV of PURPA authorizes the Department of Energy (DOE) to provide loans to all types of developers for feasibility studies and the cost of the licensing process for small scale hydroelectric projects located at existing sites of 25 megawatts or less which facilities are not currently generating electricity. DOE has issued regulations

concerning these loan provisions and Mr. Hymer who appears later in this program will discuss in detail the loan process of DOE. Thirdly, Section 213 of PURPA authorizes the FERC to issue exemptions from the federal licensing process to certain "conduit" hydroelectric facilities. Again, FERC has issued expediting regulations under the conduit hydro provisions of PURPA.

In an effort to cut federal red tape further, Congress enacted Section 408 of the Energy Security Act of 1980 (SYNFUELS). Section 408 permits the FERC to exempt from the federal licensing process small scale hydroelectric projects of 5 megawatts or less located at existing impoundments. At the time of the preparation of this abstract FERC has not issued proposed regulations under this Section. However, by the time this paper is delivered at the Conference of Renewable Energy Technology, it is expected that FERC will have issued the regulations under Section 408 of Synfuels and, accordingly, the main body of the paper will contain a discussion of these regulations.

II. THE PROBLEM OF POWER MARKETING AND THE MONOPSONY CASE

Prior to the enactment of Title II of PURPA small producers and cogenerators of electric power were confronted by what is known as the "monopsony market". In this market, a variety of sellers are confronted by a single buyer whose decision to purchase the goods or services is constrained only by its own internal constraint of maximizing profit. As a result of this monopsony condition, small power producers and cogenerators have been forced to sell their power at "dump power" rates to the electric utility system.

Title II of PURPA attempts to remedy this situation. It guarantees a market for the power of small power producers and cogenerators at rates that are just and reasonable. Under the statute this guarantee extends to certain "qualifying" facilities. In addition, Title II of PURPA authorizes FERC to exempt small power producers of a certain size from traditional, pervasive public utility regulation at the state level. FERC has been required under Title II of PURPA to issue regulations on the definition of qualifying facilities, standards for rate making and exemptions from public utility regulation. The most important provision of these regulations are those provisions dealing with the standard for the determination of the rates to be payed a small scale hydroelectric project by integrated electric utility systems.

III. CAPITOL FORMATION AND CAPITOL REQUIREMENTS OF SMALL SCALE HYDROELECTRIC FACILITIES

To the extent that Title II of PURPA, the FERC regulations and the activities of the state regulatory authorities increase the price at which power from small scale hydroelectric facilities may be sold to integrated electric utility systems more and more small scale hydroelectric projects will become feasible. However, despite the guarantee of a market contained in Title II of PURPA, risks remain which constrain access to financing. The Energy Tax Act of 1978 contained no provisions for federal tax incentives to small scale hydroelectric developers. This situation has been remedied by passage of the Crude Oil Windfall Profits Tax Act of 1980 (COWPTA). Under COWPTA, small scale hydroelectric facilities of 25 megawatts or less located at existing dams are eligible for the basic 10 percent investment tax credit and an additional 11 percent energy tax credit. Investments made through the end of 1985 are eligible. Also any investments made between 1985 and 1988, should a federal license application be pending for the project with FERC, are eligible for the tax credit. Sites of from 25 megawatts to 125 megawatts are eligible for a declining percentage of the energy tax credit.

Because municipalities, irrigation districts and other public entities and political subdivisions have expressed strong interest in developing small scale hydroelectric projects at facilities owned or operated by these public entities, attention was directed to the availability of tax exempt financing. As might be expected, on examination of the industrial development bond provisions of the Internal Revenue Code, there was a great uncertainty as to what projects could be financed through tax exempt financing under the Internal Revenue Code. COWPTA in large measure remedies the uncertainties created by the Internal Revenue Code. Now, the entire issue necessary to finance a project at an existing site of 25 megawatts or less will be tax exempt if the political subdivision owned the facility as of October 15, 1979. The percentage of the issue of the bonds which is tax exempt declines for projects ranging in size of in excess of 25 megawatts to 125 megawatts.

At the writing of this abstract, the Joint Committee on Taxation of the United States Congress has not issued its "General Explanation" or "Bluebook" on the hydroelectric provisions of COWPTA. However, by the time this paper is delivered at the renewable energy technology conference, the "Bluebook" will have been prepared and circulated. This paper will contain a discussion of the "Bluebook".

Dup

SMALL SCALE HYDROELECTRIC DEVELOPMENT AND THE ENVIRONMENT: ISSUES, CHALLENGE, AND OPPORTUNITY

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A small scale hydroelectric (SSH) facility is defined as an existing dam that can be retrofitted to produce 25 MW or less capacity. An estimate of the total SSH potential in the United States indicates there are 4,979 sites with 8,775 MW capacity and 25,126 GWh average annual energy[2]. Appropriate site-specific analyses of environmental constraints to SSH development are necessary to ensure that this resource is developed in an environmentally acceptable manner.

ISSUES

Some of the major environmental issues that must be analyzed to determine potential for adverse impact at SSH sites include dredging, fish passage, water level fluctuation, and instream (minimum) flow. If dredging is required to reclaim reservoir storage capacity, to clear intake structures, or to construct/repair powerhouses, tailraces, and headraces, adverse impacts on aquatic systems can occur. Major sources of these impacts include increased suspended solids and siltation, habitat removal, changes in water and sediment chemistry including mobilization of contaminants, and dredged material disposal practices[3]. Increased suspended solids and turbidity can reduce photosynthesis, clog the gills or feeding structures of fish, mussels, and zooplankton, and reduce fish spawning success and production of benthic organisms. The substrate material removed during dredging may alter the habitat available for benthic organisms. If the sediments to be dredged contain contaminants (pesticides, metals, etc.) which will be released to the water column, toxic effects on aquatic biota should be evaluated. Mitigation measures include proper choice of dredging equipment and the scheduling of dredging operations at times of year when biological productivity is lowest.

If development of a SSH site will interfere with both upstream and downstream movement of migratory fish species, the need for fish passage facilities must be evaluated. The capability to design facilities to pass fish upstream around dams (fishways, fish locks, fish lifts) is available. Care must be taken, however, to ensure that species-specific biological criteria (swimming speed, behavior, water quality requirements) are incorporated into design specifications[4]. Basic unit costs for passage facilities range from approximately $6,000 to $30,000 per vertical foot (30.5 cm) of head. The possible adverse impact on fish populations resulting from downstream migrants passing through turbines also warrants concern. Most available data on turbine mortality come from studies of larger scale hydro facilities. Information on mortality from passage through tube and bulb turbines is not readily available. Clearly, research on the significance of this issue for SSH sites and an evaluation of mitigation techniques are needed.

Water level fluctuation from operating a SSH facility in a store and release (peaking) mode can adversely affect aquatic biota in both reservoirs and tailwaters[5]. Potential impacts on physical and ehcmical characteristics of reservoirs include resuspension and redistribution of bank and bed sediment; leaching of soluble orga... matter from sediment in the littoral zone; and changes in water quality resulting

from changes in sediment and nutrient trap efficiency. Potential impacts on reservoir biota include habitat destruction and the resulting partial or total loss of aquatic species; changes in habitat quality which result in reduced standing crop and production of aquatic biota; and shifts in species diversity. The potential physical effects of water level fluctuation on tailwaters are streambed and bank erosion and water quality problems related to resuspension and redistribution of these materials. Aquatic populations below dams can be adversely affected by changes in (1) current velocity, (2) habitat availability, and (3) food supply. The need to maintain instream flows for protection of fish and wildlife resources is a critical issue at peaking facilities. Considerable research is in progress to develop criteria to establish instream flow needs.

CHALLENGE AND OPPORTUNITY

From the environmental perspective a major challenge in developing SSH sites is to determine the magnitude of environmental studies necessary to evaluate the significance of potential impacts at the pre-feasibility study phase. Financial resources can then be optimized to address significant issues that may require mitigation. Many SSH sites can be developed with minimal adverse impact, or mitigation plans can be included to ensure environmental acceptability. With proper front-end planning and communication with regulatory authorities and interested parties, and with an appropriate level of site-specific analysis, environmental issues should not be an absolute barrier to SSH development at many sites. Possible exceptions to this generalization include development of sites on rivers designated as wild and scenic, at sites where critical habitat for endangered species is an issue, or at sites where satisfactory mitigation for passing migratory fishes is not feasible. Development of the SSH resource represents a good energy investment. Net energy analysis of 7 Department of Energy SSH demonstration projects revealed net energy ratios (output:input) between 8.6 and 32.9:1. Development of SSH sites can be more energy efficient than other electrical generating methods[6]. Hydroelectric power represents a renewable energy resource. The estimated SSH resource in the United States represents approximately 1% of existing total installed electrical capacity from all sources. The attributes of renewable energy, good energy investment, and the emphasis on existing dams as opposed to new dam construction are positive features from the environmental standpoint.

[1]Research sponsored by the Office of Hydroelectric Resources Development, U. S. Department of Energy, under contract W-7405-eng-26 with Union Carbide Corporation. Environmental Sciences Division, ORNL.
[2]U. S. Army Corps of Engineers. 1979. Preliminary Estimate of Hydropower Resources. Institute for Water Resources (Ft. Belvoir, Virginia) and Hydrologic Engineering Center (Davis, California).
[3]Loar, J. M., L. L. Dye, R. R. Turner, and S. G. Hildebrand. 1980. ORNL/TM-7228 (July, 1980), Oak Ridge National Laboratory, Oak Ridge, TN 37830.
[4]Hildebrand, S. G. (Editor). 1980. ORNL/TM-7396 (August, 1980), Oak Ridge National Laboratory, Oak Ridge, TN 37830.
[5]Hildebrand, S. G. (Editor). 1980. ORNL/TM-7453 (In Press), Oak Ridge National Laboratory, Oak Ridge, TN 37830
[6]Gilliland, M. W., J. M. Klopatek, and S. G. Hildebrand. 1980. Science (submitted).

PRE

STATE LEGISLATIVE ISSUES IN SMALL-SCALE HYDROPOWER

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Denver, Colorado, U.S.A.

The NCSL Small-Scale Hydroelectric Project seeks to assist the state legislatures in examining issues relating to small-scale hydropower and in developing policies to encourage efficient development of this promising domestic energy source. This assistance includes education, issue identification, policy analysis and suggestion of legislative options appropriate to a particular state. The project is designed to supplement the efforts of in-house legislative staff in this regard.

The need for well-defined state policies is crucial with regard to both obstacles and incentives. Those areas which generally warrant legislative attention include licensing procedures, power marketing, finance and taxation, and water law. This paper summarizes the issues of concern in each of these policy areas.

Federal Role

While the scope for state action to promote small-scale hydropower is large, the strong federal role must be kept in mind. Under the Federal Power Act, the Federal Energy Regulatory Commission (FERC) has jurisdiction over virtually all potential projects. Through its licensing process, the FERC ensures that projects comply with both state and federal laws, primarily those relating to the environment.

In addition, the FERC was directed by the Public Utility Regulatory Policies Act (PURPA) to establish guidelines in several areas relating to small-scale hydro utility matters. These include interconnection of a project to existing utility grids, wheeling and purchase of power output, and exemption from certain federal and state utility regulation. Implementation of these guidelines is largely a state affair, however.

Licensing Procedures

Environmental regulation is frequently a major obstacle to small-scale hydropower development, particularly by small entrepreneurs. Overlapping agency jurisdictions, redundant permit requirements and delays in agency decisions can create a severe impediment to development. Some marginally economic projects may be made infeasible due to the regulatory burden.

In this regard, it should be noted that small-scale hydro development, emphasizing run-of-the-river projects at existing facilities, has a generally benign environmental impact. State legislatures may wish to establish criteria and thresholds which allow certain projects to proceed without triggering full-blown environmental regulation. Fish ladder requirements are especially significant.

In addition, many streamlining options are available to reduce the regulatory burden, including elimination of redundant permit requirements, time frames for agency decisions, interagency coordination and assistance to license applicants. Licensing procedures may be restructured using a clearinghouse, lead or one-stop agency approach. The goal is to centralize and coordinate the permitting process.

Power Marketing

The ability to market power output from a small-scale hydropower project at a reasonable price is crucial to its economic feasibility. Utility developers will probably utilize the power output, but entrepreneurs will seek to sell excess power beyond their own consumption. If such sales are to an existing utility, the provisions of PURPA apply. That is, the utility must interconnect to the project and purchase power output at marginal prices. These rates are to be established by state utility commissions.

On the other hand, if the developer wishes to make retail sales to selected customers, wheeling and utility franchise matters must be addressed. That is, the state may require utilities to wheel power across their lines to retail customers (wheeling for wholesale is probably under FERC jurisdiction) with appropriate safeguards and payments. And, such operations would probably need to be exempted from utility franchise area acts.

Taxation and Financing

The state tax of major consequence to small-scale hydropower is the ad valorem property tax. This tax may constitute a severe financial burden during initial retrofitting of a site or during periods of low stream flow--and, hence, no project revenues. Mechanisms of exemption, deferral or in-lieu-of taxation should be considered by the states.

Since small-scale hydropower is a capital-intensive undertaking, some degree of public financed assistance may be necessary to achieve development. Assistance to the private sector may take the form of grants or loans, especially low-interest, forgivable loans. Constitutional limitations may be important in this regard.

Public development, via municipalities, special districts or power authorities, is another attractive option due to the availability of tax-exempt financing. The charters of such political entities, especially relating to bonding powers, should be examined to ensure adequate authority to develop small-scale hydropower. Direct state assistance or bond guarantees may also be considered to enhance public financing avenues.

Water Law

There are two major water doctrines in the United States. Under the riparian (eastern) theory, water rights are derived from ownership of adjacent land and are conditioned by reasonable use requirements. Under the appropriation (western) theory, water rights are awarded to users who divert the water for beneficial use--independent of land ownership--and are subject to a priority regime.

Obtaining the necessary water rights is a basic prerequisite to small-scale hydropower development. State water laws should be reviewed to ensure compatibility with and adequate protection for small-scale hydropower projects. This includes establishing minimum stream flow requirements with a proper balance between environmental and power generation purposes.

Conclusion

Aggressive promotion of small-scale hydropower by the states can significantly foster development. Small-scale hydropower potential should be incorporated into state energy plans and public information and assistance made available. Most importantly, the above policy areas should be comprehensively reviewed.

HYDROPOWER AND THE DEVELOPER

Al E. Hymer
Brent F. Russell
Idaho National Engineering Laboratory
Idaho Falls, Idaho, U.S.A.

The U.S. Department of Energy is assisting in the reactivation and development of existing dams through the Small Hydropower Loan Program that provides low interest money to study the feasibility of developing or licensing of a small hydropower facility. A feature of the Program is that under certain circumstances, the loan may be forgiven. The Loan Program was authorized by Title IV of the Public Utility Regulatory Policies Act (PURPA) of 1978 and recently modified by the Energy Security Act of 1980. To qualify for a loan under this Program, all applicants must satisfy certain qualification criteria required by law. These criteria are:

1) Each proposal must address an existing dam or a conduit system that was constructed prior to April 20, 1977, or certain natural water features.

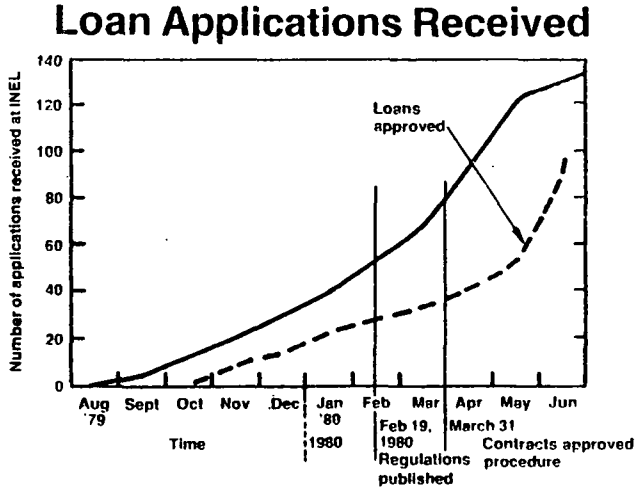
2) The proposed power capacity will be not more than 30,000 kilowatts (kW) nor less than 100kW.

3) The site is not currently being used to generate power.

The Loan Program will provide up to 90% of the funds required to complete a feasibility study and/or related licensing tasks. A project could receive up to $100,000 ($50,000/activity) for both the feasibility study and licensing costs. If the feasibility study indicates that the site is either technically or economically not feasible or environmentally unacceptable, then the loan may be forgiven. Additionally, the loan may be forgiven if the borrower is unable to obtain a necessary license or any right necessary to construct and operate the project for reasons beyond the borrower's control. This forgivable clause in the Regulations removes most of the front-end risk involved in developing a site.

Since the Energy Security Act was made law in July, 1980, the Loan Program will be able to accommodate loan applications with a proposed installed capacity of up to 30,000kW and clearly address a site on a conduit system or certain natural water features. The major determining criteria for sites utilizing a certain natural water feature will be the environmental impacts associated with the site development.

FIGURE I



Interest in the Hydropower Loan Program has increased since the Rules and Regulations and contracting procedures have been established as indicated in Figure 1. There have been an average of 30 applications received per month for feasibility study or licensing loans. The proposed

capacity for these projects has ranged from 130kW to 15,000kW, and the average loan amount for a feasibility study is $32,000 with an average proposed capacity of 2,500kW (about $13/kW). Table 1 presents a regional analysis of the average loan amount and project size. Approximately 35% of all the loan applications have been received from cities and counties, 18% from cooperatives, and 16% from individuals/partnerships. A complete breakdown of types of applicants is presented in Table 2.

TABLE I

REGION	AVERAGE LOAN AMOUNT	AVERAGE SIZE PROJECT (kW)
DOE Region I - New England	$34,400	2,500kW ($14/kW)
DOE Region II - Middle Atlantic	31,000	400kW ($78/kW)
DOE Region III - South Atlantic	34,500	3,900kW ($9/kW)
DOE Region IV - East South Central	36,000	2,700kW ($13/kW)
DOE Region V - East North Central	20,650	1,000kW ($21/kW)
DOE Region VI - West South Central	38,000	4,400kW ($9/kW)
DOE Region VII - Central	17,400	525kW ($33/kW)
DOE Region VIII - Mountain	25,800	1,800kW ($14/kW)
DOE Region IX - South Pacific	34,000	2,500kW ($14/kW)
DOE Region X - North Pacific	29,150	2,500kW ($12/kW)
National	$32,000	2,500kW ($13/kW)

TABLE II

TYPE OF APPLICANT VS. AVERAGE PROPOSED INSTALLED CAPACITY

TYPE OF APPLICANT	% OF LOAN APPLICANTS	AVERAGE PROPOSED INSTALLED CAPACITY
Cities and Counties	35%	2,700kW
Cooperatives	18%	6,700kW
Individuals/Partnerships	16%	1,500kW
Irrigation Districts	15%	2,800kW
Corporations	10%	2,400kW
States/State Agencies	4%	3,000kW
Non Profit	2%	3,600kW
	100%	3,200kW

The application requirements must include the amount of loan requested, a description of key tasks with schedule, estimated costs by major tasks, applicant history, experience with hydropower development, financial statements, documentation of applicant authority, and Federal Energy Regulatory Commission (FERC) status. The application should provide a narrative description of the proposed site including number, physical composition, dimension, age, and condition of the structures. Other aspects to be presented are details on transmission lines, power capacity, energy, probable customers, sales price, stream characteristics, maps

and pictures, dam safety, anticipated environmental impacts, right of access, water rights, and a copy of the notification to state area clearinghouses.

Loans will be awarded on a first come, first serve basis. Generally, a loan will be given if there exists a reasonable likelihood that the applicant or person who will perform the study is capable of completing the study and project development; the project is technically and economically feasible and environmentally acceptable; the applicant is capable of repaying the loan; and the site is not contested.

The loan terms are 7 3/8% interest to be paid back in ten (10) years. On the fourth (4th) anniversary date, the accrued interest, which will include interest charged on unpaid interest, shall be added to the outstanding principle balance and 1/7 of that total shall be due and payable. Each anniversary date thereafter, the same computation is made and 1/7 of that amount due. Prepayments may be made at any time without penalty.

Contested sites are becoming an increasing problem as interest in small hydropower development in the United States is stimulated. The Department of Energy will not provide a loan to an applicant if the site is known to be contested. Consequently, the status of a FERC Preliminary Permit has been utilized as a decision point in most cases. DOE will not provide a loan to an applicant if a Preliminary Permit has not been obtained if:

a) The applicant wishes to develop a federally owned dam, or
b) The applicant does not own the site.

An applicant who owns the site or a municipality is not required to obtain a Preliminary Permit prior to issuance of the loan.

The data accumulated by the feasibility studies completed under the Loan Program is entered into a Hydroeconomic and Environmental Data Base maintained at Idaho Falls. The Data Base will provide long term tracking of hydropower projects, costs, and associated environmental concerns related to the development of hydroelectric facilities.

Additional information regarding the Small Hydropower Loan Program can be obtained from any of the ten (10) Department of Energy Regional Offices located in Boston, New York, Atlanta, Chicago, Dallas, Kansas City, Lakewood (CO), San Francisco, and Seattle, or from the DOE Hydroelectric Loan Program in Idaho Falls, Idaho.

PRE

DOE DEMONSTRATION PROJECTS AND ENGINEERING DEVELOPMENT

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Idaho Falls, Idaho, U.S.A.

This paper presents the activities of two phases of the Department of Energy's (DOE) Small Hydroelectric Development Program; Demonstration Projects and Engineering Development.

The objective of the DOE Small Hydroelectric Development Program is to provide appropriate assistance to the private and public sectors to accelerate the development and commercialization of hydroelectric power at existing dams, that are amenable to retrofitting or adding of hydroelectric equipment. The Small Hydroelectric Program is defined as being applicable to those existing sites having a total potential power capacity of 30 MW or less. No hydraulic head limitation exists for the DOE program.

Demonstration Projects

The goal of the demonstration projects is to show that the development of small hydroelectric power is an economical source of energy, and by utilizing existing dams, power can be brought on line in 18 to 36 months. By demonstrating that an economically viable small-scale hydropower plant can be built with available technology, the program will provide a number of benefits. It will (1) encourage and expedite the utilization of a renewable energy resource, (2) contribute to a conservation program by decreasing the demands on finite fossil-fuel resources, (3) provide guidelines to determine the lower limit that small-scale hydroelectric potential can be considered viable, and (4) provide information about costs and performance on which to base future evaluations and equipment selection.

As a first step toward demonstration projects, DOE issued a Program Reserach and Development Announcement on December 2, 1977 (PRDA-ET-78-D-07-1705) for feasibility assessments. These feasibility assessments were to evaluate the economic, technical, and environmental feasibility of hydroelectric additions at a variety of existing small-scale dam sites. Although 189 proposals were evaluated, available funding allowed DOE to award only 54 cooperative agreements to perform feasibility assessments at selected sites distributed throughout the nation. Approximately 70% of these sites were shown to be economically feasible to develop after completion of the assessments.

DOE is presently cost sharing in 22 small hydroelectric demonstration projects of various kinds and sizes, located in 20 different states. DOE's first demonstration project was arranged in January 1978 with the City of Idaho Falls. To expand DOE-supported demonstration to other representative sites throughout the nation, DOE issued two Program Opportunity Notices (PON) announcing the availability of financial support for the design, construction and operation of small-scale hydroelectric plants at existing dams. The first solicitation (PON-ET-78-N-07-1711) was issued on June 23, 1978, and is referred to as PON-I. Funds were available only for sites where feasibility assessments had been completed. This solicitation resulted in 23 proposals, and available funds allowed DOE to award seven cooperative agreements.

The second PON solicitation was issued on June 22, 1979, (PON-DE-PN-07-79-ID-12043). This solicitation was scheduled to coincide with the completion of the site feasibility assessments and conceptual designs done under the DOE-funded PRDA feasibility assessments. Other potential projects, which had completed feasibility assessments, were also eligible to make proposals. This solicitation, referred to as PON-II, resulted in 47 proposals. Available funds allowed DOE to award 14 cooperative agreements.

Engineering Development

The Engineering Development Program supports the development of technologies needed to accelerate commercialization of small hydropower. Funding is provided to develop new technologies, improve existing technologies, and employ novel applications of existing related technologies. Much of the existing small hydropower potential is marginally economical or uneconomical to develop. Innovations from a program such as the Engineering Development Program are essential if the lower limit of economic feasibility is to be reduced sufficiently to allow commercial development of some portions of the remaining small hydropower resource.

A survey of the feasibility studies submitted in response to the Program Research and Development Announcement, PRDA-ET-78-D-07-1706, issued in 1978, was performed to determine costs of small hydropower projects. This survey was performed using data from sites judged to be feasible and infeasible, in order to highlight areas where improvements could substantially improve site economics. These cost comparisons highlighted the high costs of the equipment and civil works for the lower head and power range of small hydropower. It also emphasized the higher percentage of total costs made up by the equipment. These comparisons spotlighted the need for cost reducing innovations to make small hydropower more economical.

A review of the Corps of Engineers Inventory of Hydropower Resources shows that over half the existing dams, 25 MW and below, have heads less than 26 ft. (8m) and 70% have power producing capacilities less than 1500 kW. Improvements in the economics of small hydropower sites will, therefore, have an impact on a large number of existing dams. While the program is not directed at only the low head and power sites, these sites do highlight the uneconomical areas of small hydropower and benefits gained can be applied to all sites .

The Engineering Development subprogram has been directed towards improvements in a number of areas which are aimed at reducing the costs of small hydropower. These improvements are classified in the following areas:

1. Equipment and site structures;
2. Plant operations;
3. System management and resource assessment.

There are many aspects in the Engineering Development Program that will be pursued in the future as funds are available. The basic approach to fund these projects is to provide financial support and incentives in such a manner as to promote the greatest interest and participation of private enterprise. It is not the intent of the program to conduct pure research per se, but, through the judicious allocations of funds, to encourage and promote the development of simple and less expensive hydropower techniques and equipment by the private sector.

PRE

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BULB TURBINE INSTALLATION FOR IDAHO FALLS

Jeffrey S. Paine
Chief Engineer
City of Idaho Falls Electric Division
Idaho Falls, Idaho, U.S.A.

The Idaho Falls Bulb Turbine Project is a key demonstration project in the United States Department of Energy's low head hydro-electric program. The project involves the reconstruction of three existing low head hydro-electric plants located on the Snake River in South Eastern Idaho. This project spurred DOE's entry into the low head hydro field to act as a stimulant to rapid development of this nations low head hydro potential.

Idaho Falls is located in Southeast Idaho approximately one-hundred and twenty miles South and West of Yellowstone National Park and is built along the banks of the South Fork of the Snake River. The City has operated a municipal electric system since 1901. The initial power supply was obtained from a small generator installed on an irrigation canal in the heart of the City. During the years 1910 through 1945, the City expanded it's generation to three (3) small plants distributed over a seven mile reach of the main river channel within the area of the City. These three plants produced a total of 7,000 kilowatts when they were in good condition, however, the concrete in the plants had deteriorated badly over the years. Major repairs and replacements were necessary.

Prior to 1976, these three plants produced about five-percent (5%) of the City's total energy requirements. The additional energy needed for loads in excess of this generation is purchased from the Bonneville Power Administration (BPA). BPA may not be able to provide additional new power after 1983 and as a result the City must seek other sources of power and energy.

In June of 1976, the Teton Dam failed upstream of Idaho Falls. The resulting flood waters caused further damage to the power plant structures and made one of the plants total inoperative. This occurrence coupled with the need of additional power supplies prompted the decision to examine the feasibility of reconstructing the plants to expand their production capabilities.

The results of the feasibility studies showed that by improved use of stream flows, more than three (3) times the previous power could be produced. This would be accomplished by installing a new eight (8) megawatt generator at each plant site and completely reconstructing the diversion systems. No significant change will be made in head or upstream pool elevations.

Several turbine generator types were investigated for this re-development. Bulb turbines were finally selected primarily because they are physically smaller than vertical shaft systems of the same capacity. The smaller size and less complicated water passage forming required for this machine will result in powerhouses costing less than for comparable vertical shaft machines. These

savings will more than offset the slightly higher cost of the turbine generator. For this size machine, sufficient space is available inside the bulb to allow access to maintenance personnel.

Much attention was given to the economics of the project. The project will cost approximately $58 million which includes approximately $10 million in capitalized interest and bond retirement and a renewal and replacement fund. This results in a cost of approximately $2400 per kilowatt of installed capacity. This substantially exceeds the installed cost per kilowatt for traditional thermal systems. The project's merits however, are established on the basis of the cost per kilowatt hour, not the installed cost per kilowatt.

The project cost per kilowatt hour is presently estimated at 2.5¢. This compares with projected thermal project energy costs in excess of 3.5¢ per kilowatt hour although they will normally have lower initial costs per installed kilowatt.

The project is presently under construction. The first machine is scheduled for initial operation in December of 1981. The second is to come on line in March of 1982 with the third machine to be operational in June of 1982.

A project of this type is very interesting to be involved with. If you undertake such a project be prepared for an interesting and very worthwhile experience. Understand however that there are many special services which you will likely require such as special attorney services including water right specialists, and bond specialists as well as underwriters, financial consultants, project design engineers, auditors, independent engineers to perform financial analysis and a project management team to see you through the construction.

PRE

SMALL SCALE HYDRO PLANT AT AN EXISTING DAM: THE GOODYEAR LAKE GENERATING STATION

missing

F. W. E. Stapenhorst
President
F. W. E. Stapenhorst, Inc.
Pointe-Claire, Quebec, Canada

F. W. E. Stapenhorst, Inc. acquired the disused Goodyear Lake Station, from the New York Electric & Gas Corporation, for the purpose of rehabilitation with modern turbine-generating equipment.

With the interest of the Department of Energy, this project became a demonstration project, with a grant from the Department of $245,000. As such, it is the first station officially opened, under the auspices of the Department of Energy.

With the little knowledge and guidance available for small scale hydro at the time of our initial interest, the front time and the front costs consumed for the project to become on-going was very considerable.

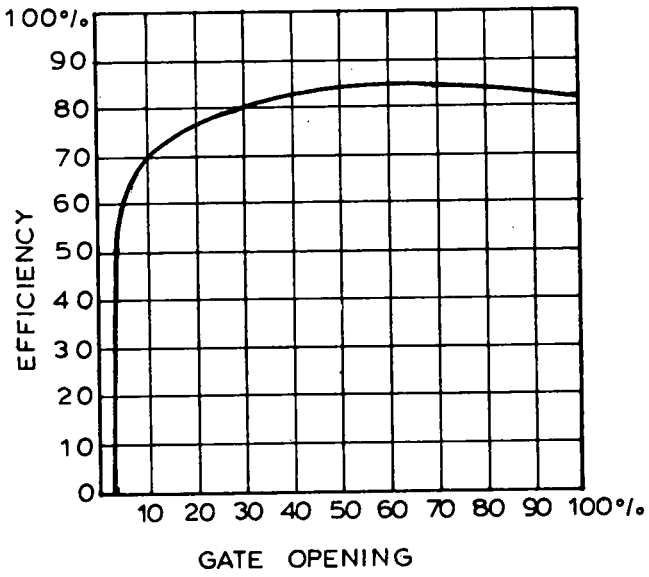
Let us list a few of the items concerned:

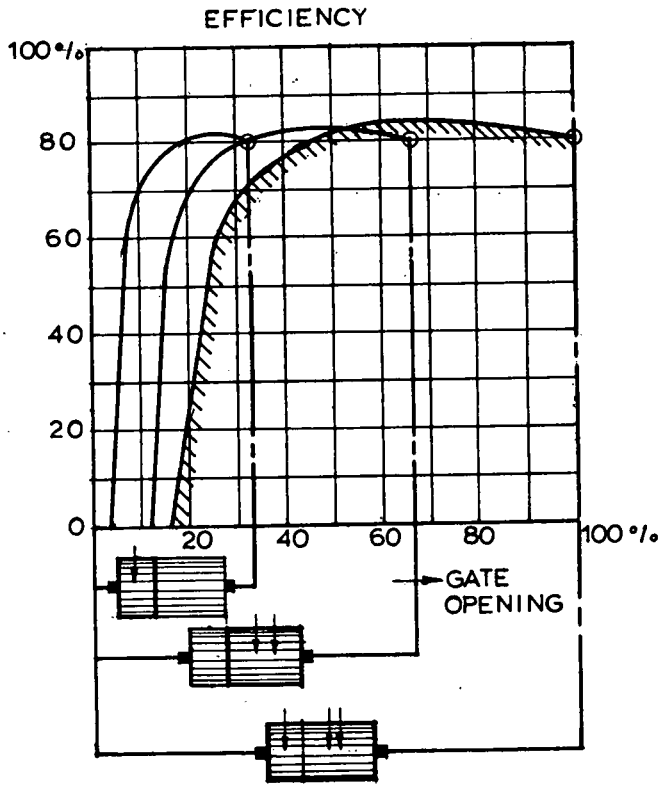
- Preparation of license (now simplified)
- Environmental impact statement
- Negotiations with the utility in respect to rates and other terms of the power contract.

With a license issued and finance secured through an issue of tax-free bonds, Stapenhorst carried out the rehabilitation of civil works and modifications to the structures with direct labour, over a period of 15 months.

With greatly varying flow conditions, two Ossberger Cross-Flow turbines of 1000 HP each were installed to generate approximately 7.5 million kwhours per year. The cross-flow turbines are an ideal application for such run-of-the-river applications, maintaining a flat efficiency curve through a wide range. Noteworthy, is the electronic control equipment, which automatically governs the turbines with the available water quantity. Automatic shut-down and start-up is given, in case of collapse of the grid, with re-start after restoration, same as when the water level has reached its minimum, with re-start, when water becomes available again.

OSSBERGER CROSS-FLOW TURBINE





COSTS OF PROJECT

Front end costs	235,000
Equipment & Installation	625,000
Rehabilitation of Civil Works	330,000
Supporting Engineering	119,000
Capitalized Interest	75,000
Financing, Legal, Etc.	172,000
Procurement Expenses	70,000
Debt Service Reserve Fund	50,000
Miscellaneous	84,254
Total Project Cost	$1,760,254

Financed as follows:

DOE Grant	245,000
F. W. E. Stapenhorst, Inc.	515,254
Bond Issue	1,000,000
Total	$1,760,254

In result, the Goodyear Lake project has proven, that small scale hydro is viable, and it is hoped, that many more projects will get on the way, as a contribution to the energy crisis.

PRE

SMALL SCALE HYDRO DEVELOPMENT IN ALASKA

Eric P. Yould
Executive Director
Alaska Power Authority
Anchorage, Alaska

Alaska, national leader in reserves of oil, gas, coal, and other energy resources, is looking to hydropower to provide the majority of its future domestic energy needs. In fact, this is not an unrealistic goal. Federal agencies which have inventoried some of Alaska's resources have concluded that more than 40% of the Nation's untapped hydropower potential resides in Alaska alone. Presently only 13% of Alaska's electric energy demands are provided for by hydropower. The balance of electrical energy is provided by natural gas in the Anchorage area and diesel generation throughout much of the rest of the state. The electric rates throughout the state range from a low of 7 cents/kwh in Anchorage to as much as 50 cents/kwh for many of the remote villages.

TABLE I. Projects in Various Stages of Development

Project	Size (KW)
Dayebas	5,000
Elva	1,500
Larsen Bay	1,100
Elim	125
Akutan	200
Crater Lake	389
Kaltag	155
Scammon Bay	285
Shungnak	1,200
Kiana	460
Old Harbor	600
Port Lions	180
Black Bear	5,000
Grayling	230
Swan Lake	22,000
Tyee Lake	20,000
Terror Lake	20,000
Green Lake	13,500
Solomon Gulch	12,000
Kisaralik	30,000
Tazimina	18,000
Power Creek	5,000
Grant Lake	6,000

In order to lower the cost of power statewide, the Alaska Power Authority is pursuing an aggresive program that will see as much as $7 billion expended on hydropower construction alone during the next decade and a half. While the majority of this expenditure will go toward a large project to satsify the needs of Anchorage and Fairbanks, the small rural communities will benefit as well. Table I is a listing of small hydropower projects presently in various stages of the planning process.

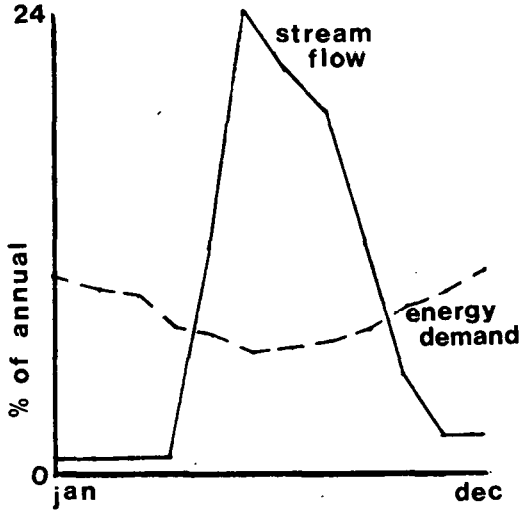
More projects will be identified as community demands and resource assessments are accomplished. None of the villages are interconnected, and most of the projected load demands are small. In addition, as illustrated in Figure 1, load demands for the villages are generally highest during the long winter months when streamflow is at its lowest. Consequently, despite the abundance of hydropower potential throughout the state, communities are generally limited to considering high head storage projects in close proximity to the actual load centers. This is in contrast to the low head run-of-the-river development which is becoming popular elsewhere.

This set of circumstances coupled with the high cost of construction in remote Alaskan communities generally results in costs per unit installed capacity at considerably higher than that which is traditionally considered feasible

throughout the remainder of the United States. However, given the high existing cost of power and the foreseeable future, the life cycle benefits even from this expensive hydropower are significant. Thus, while it exports its vast petroleum reserves to the remainder of the United States, Alaska is pursuing a program that will insure a legacy of non-inflating energy for its future generations.

Figure 1

Seasonal Distribution of Streamflow
and Energy Demand in Alaska



SECTION 10

ELECTRIC ENERGY SYSTEMS

ELECTRIC ENERGY SYSTEMS

Program Chairman: *James A. Smith,* General Electric Company
DOE Advisor: *Kenneth W. Klein*
Overview Presentation: Wednesday, December 10, 1:30 P.M.

"Comprehensive Overview Paper on Electric Energy Systems for Renewable Energy Technologies" 2-69
Kenneth W. Klein, DOE, and *James A. Smith,* General Electric Company

SESSION I: Wednesday P.M.
Electric Systems

"System vs Dedicated Storage" 10-1
W. D. Marsh and J. L. Oplinger, General Electric Company
"Load-Leveling Battery Systems—Testing and Demonstration 10-3
Peter A. Lewis, Public Service Electric and Gas Company, and *John N. Keen,* Wolverine Electric Cooperative, Inc.
"Fuel Cells and Biomass" 10-5
B. S. Baker and D. Nault, Energy Research Corporation
"Power Conditioning" 10-7
Peter Wood, Westinghouse Electric Corporation

SESSION II: Thursday A.M.
System Control and Integration

"Electric System Impacts of Dispersed Energy Technologies" 10-9
William T. Miles and Fred S. Ma, System Control, Inc.
"The Influence of Dispersed Storage and Generation on Communication Requirements for Load Management and Distribution Automation & Control" 10-12
Raymond K. Adams, Oak Ridge National Laboratory, and *Thomas W. Reddoch,* University of Tennessee
"OTEC Integration" ..... *
Rafael Llavina, Jr., Puerto Rico Electric Power Authority
"Wind Integration via Variable Speeds" 10-14
T. A. Lipo and S. Abd-El-Hamid, Purdue University

SESSION III: Thursday P.M.
Cable and Compact Equipment

"Interconnecting AC and DC Systems" 10-16
R. L. Hauth and G. D. Breuer, General Electric Company
"Hawaii Specific Problems – Deepwater DC Cable Transmission" 10-18
Gordon A. Chapman, Parsons Hawaii
"Integrated Design and Testing of OTEC Riser Cables" 10-20
C. A. Pieroni, J. A. Schultz, J. E. Sedon, and J. P. Kurt, Simplex Wire and Cable Company
"Bottom Cables" 10-22
Aldo S. Morello, Industrie Pirelli S.p.A., Italy
"Compact Terminal Equipment" 10-24
Frank A. Denbrock and James J. Kolb, Gilbert/Commonwealth

*Abstract not available for printing in Conference Proceedings

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SYSTEM VS. DEDICATED STORAGE

W.D. Marsh and J.L. Oplinger
General Electric Company
Schenectady, New York

Storage Characteristics

System storage refers to storage that may be freely operated to reduce the cost of fuel consumed by a utility system. It can do this only when, and to the degree that: (1), the system load has peaks and valleys, i.e. is not constant; and, (2), the thermal generating units serving the load do not all have the same fuel cost of energy production. Electric utility systems meet these conditions, although in widely varying degrees.

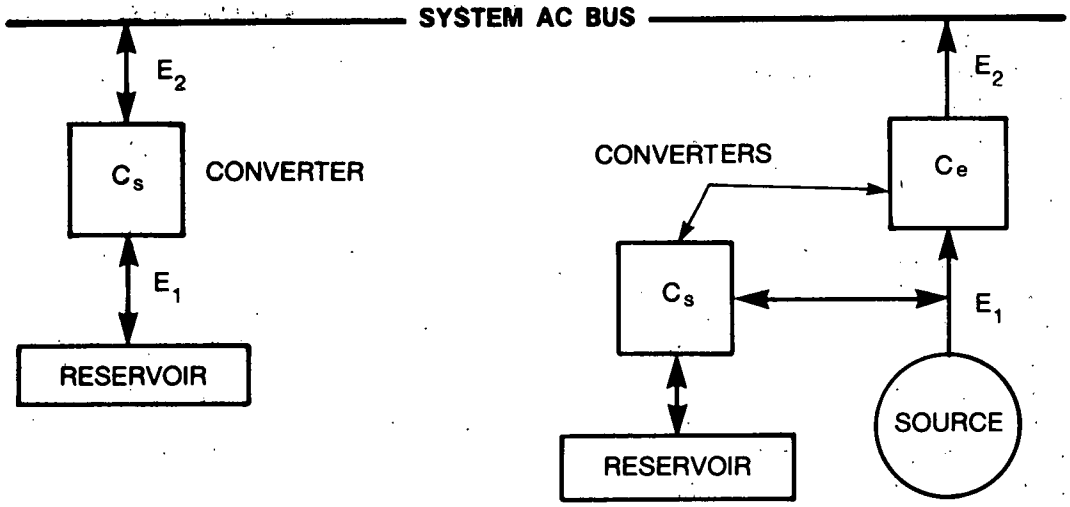


Figure 1a - System Storage

Figure 1b - Dedicated Storage

Figure 1a is a diagram of system storage, which in the U.S., has consisted only of pumped storage hydro, the convertor, C_s, comprised of a pump-turbine and a motor-generator. Because the reservoir can be large, and re-charged at any time, system storage units are usually considered to be nearly firm capacity, much as is a generator having its own energy source.

Dedicated storage is associated with an energy source as shown in Fig. 1b. An example would be a solar-thermal power plant where energy E_1 is high pressure steam. C_s is a heat exchanger to thermal storage, C_e is a turbine generator, and E_2 is AC electrical energy. Note that C_e is a non-reversible converter; it it were reversible, then the reservoir could be charged from the AC bus, and it would be system, not dedicated, storage.

The system conditions of load shape and generation cost diversity given above as requirements for economic system storage apply also to dedicated storage. The only distinguishing characteristic of dedicated storage is that it can be charged only at such times and in such amounts as the source will permit. Dedicated storage, when applied to an intermittent, renewable energy source, may enhance that source's firm capacity, but has no firm capacity of its own.

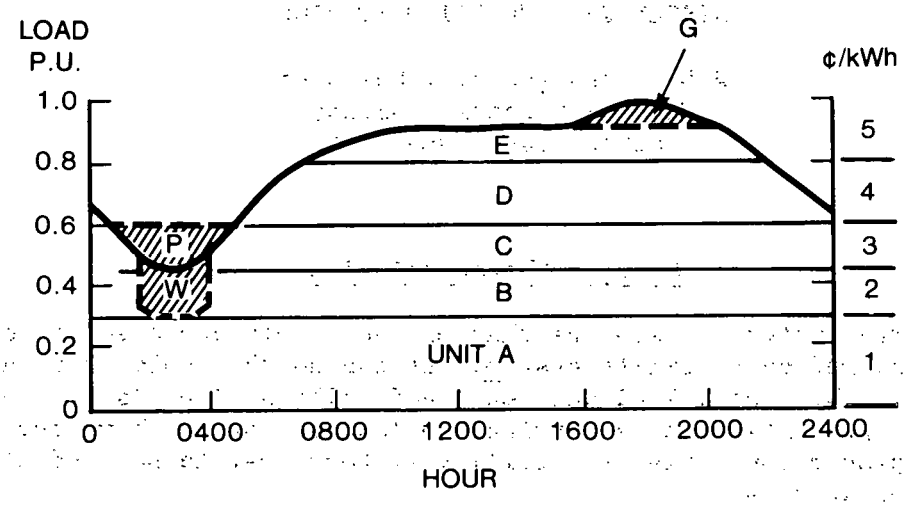


Figure 2 – Storage Operation

In Fig. 2, the solid line is a daily load curve served by units A, B, etc., at energy costs from 1 to 5¢/kWh. A dashed line encloses area "P" representing charging of system storage from 0100 to 0500 hours. The cost of this charging, entirely by unit C, at 80% round-trip efficiency, is 3/0.8 = 3.75 ¢/kWh. The discharge area G, from 1600 to 2000 hours provides a reduction in operation of unit "E" at 5 ¢/kWh. The net saving from system storage is 5-3.75 = 1.25 ¢/kWh.

The area W on Fig. 2 represents the energy of an intermittent, renewable source, e.g. wind power. Relative to the solid curve, this permits reducing the Unit B and C output, giving a saving of a little more than 2 ¢/kWh for the W unit alone. This amount of energy could be stored – by <u>either</u> system or dedicated storage - but then Units B and C would again have to operate, meaning that it is effectively their energy that would be stored. The cost of stored energy would thus be 2/0.8 = 2.5 ¢/kWh. The net saving would be 5.0-2.5 = 2.5 ¢/kWh, which is larger than the 1.25 ¢/kWh. saving calculated above for system storage alone, only because of the existence of the zero-energy-cost renewable source W.

However, if there were no renewable source output during a day, or if it occurred other than at the valley hours of the load curve, dedicated storage could operate either not at all, or not economically. System storage always has access to the valley hours for charging.

Conclusions

1. System storage can do everything that dedicated storage can do, and much more; hence,

2. There is no economic reason to associate storage with renewable energy sources on utility systems.

References: EPRI Reports ER-685, ER-978, EM-1218, RP-1271 (in preparation)

PRB

LOAD-LEVELING BATTERY SYSTEMS TESTING AND DEMONSTRATION

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More than fifty years ago, batteries were used for load-leveling on urban direct current distribution systems. With the wide spread acceptance of alternating current, advances in the development of large, efficient central stations and improvements in power distribution, batteries were relegated to relatively small scale standby power and traction applications. Today, advances in the development of batteries and solid state AC-DC power conversion equipment show promise for providing economical storage of low-cost energy generated at off-peak times for use during peak demand hours.

The national battery program sponsored by the Department of Energy (DOE) and Electric Power Research Institute (EPRI) involves the development of four battery systems (sodium-sulfur, lead-acid, lithium-iron sulfide, and zinc-halogen) for electric utility application. Major developers of these advanced battery systems are: General Electric Company, Ford Motor Co., Dow Chemical Co., C & D - a Division of Eltra; ESB - a Division of INCO; Argonne National Laboratory; Energy Development Associates - A Subsidiary of Gulf and Western Industries, and Gould, Inc. Research and development of the advanced batteries began in the early 1970's. Several projects have reached the engineering-development stage during the late 1970's and early 1980's and are continuing with fabrication and testing of full-scale cells and full-scale battery modules (50-100 kWh). Expenditures by DOE, EPRI, and the developers are about $25 million annually.

The emphasis on battery commercialization has resulted in the integrated planning and initiation of two battery projects for prototype testing and system demonstration. The first of these is the $14 million Battery Energy Storage Test (BEST) Facility which was built and is being operated by Public Service Electric and Gas Company (PSE&G) for DOE and EPRI. The second is the $15 million Storage Battery Electric Energy Demonstration (SBEED) plant.

Prototype Testing - The BEST Facility was built by PSE&G under contract to DOE and EPRI as a central station for testing and evaluating prototype modules of load-leveling batteries and their associated AC-DC power conversion equipment. This facility will provide the test data needed by both equipment developers and utility companies to make timely decisions concerning load-leveling battery system development, potential applications and economic evaluation.

Utility System Integration and Demonstration - The Wolverine and Northern Michigan Electric Cooperatives are building the Storage Battery Electric Energy Demonstration (SBEED) plant to demonstrate the economic viability of battery energy storage systems integrated with a utility network. This plant, using conventional lead acid batteries, will provide valuable data on the integration of battery systems ith the electric utility network.

The BEST Facility has the following purposes:

(a) Provide a focus for the development of battery systems including AC-DC power conversion equipment.
(b) Provide the necessary independent test data over a wide range of operating conditions to verify expected battery performance.
(c) Permit comparison of different advanced battery systems under nearly identical test conditions.
(d) Allow evaluation of battery system performance in a utility environment at an early stage of battery system development.

Construction of the BEST Facility in Hillsborough Township, New Jersey started July 1978, and the Facility began initial operation during the fall of 1980. Operation of the Facility as an integral part of the utility is considered crucial. In such an environment, batteries under test will be subjected to conditions similar to those in commercial applications including interruptions in charging, long periods of time on float, system faults and voltage fluctuation. Also, utility operating personnel will become familiar with the operation of advanced battery systems and be better able to assess the requirements for routine and breakdown maintenance. Relevant information regarding the interactions of advanced batteries power conversion equipment and the utility system will become available to assist with planning and design of full scale battery installations.

An important part of advanced battery system development is the design of control systems that will interface the utility network and the battery system. Development and testing of these control systems at the prototype level is cost effective, and provides the full range of operating requirements that a control system might encounter with large commercial units.

In parallel with the prototype testing of advanced battery systems at the BEST Facility, a full scale demonstration of battery energy storage will be conducted at the SBEED plant at Hersey, Michigan. The SBEED Plant will have a design peak output of 10 MW and a total storage capacity of 30 MWH. The SBEED Program is expected to continue for 14 years including 9½ years of commercial operation, and 4½ years for design, construction and testing.

Daverman Associates of Grand Rapids, Michigan will be Project Manager and Coordinator with responsibility for the design of all facilities with the exception of the converter. The AC-DC converter will be designed and furnished by United Technologies Corporation and the lead-acid battery will be supplied by C&D Batteries. The SBEED plant is to be located adjacent to an existing facility of the Wolverine Electric Cooperative. The plant will consist of two parallel battery strings, each comprised of 1140 cells. Each of these cells will weigh approximately 2,300 lbs. The converter will consist of several self-commutated modules, a master control system and DC protective equipment. The single structure housing for the plant will be peaked with a rigid ventilator to exhaust evolved hydrogen. During operation, it is expected that the plant will be operated Monday through Saturday because of the relatively uniform daily loads during the week.

The three main parts of the National Load Leveling Battery Development Program are expected to lead to early commercialization of advanced battery systems. Conducting these test elements in parallel is a cost effective means for providing the early introduction of advanced technologies.

PRC

FUEL CELLS AND BIOMASS

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Hawaii, with its warm climate and abundant vegetation, is a likely source of biomass type fuels. The fuel cell, being the most efficient power generator, will minimize the amount of fuel required for any application.

In this paper three aspects of energy conversion are considered -- Hawaiian sources of biomass, their conversion to gaseous and liquid fuels, and their use in fuel cells for several applications.

In Hawaii the main biomass sources are animal wastes, municipal wastes, seaweed (kelp), and other indigenous flora. U.S. Department of Agriculture statistics indicate that animal (cattle) and human waste alone could provide fuel equivalents equal to about 10% of Hawaiian ground transportation requirements if used in fuel cell powered vehicles.

It is important to match fuel form with application. Gaseous fuels are particularly suitable for central electric power and on-site electric power generating stations; liquid fuels are more suitable for transportation use. This matching is shown schematically in Figure 1.

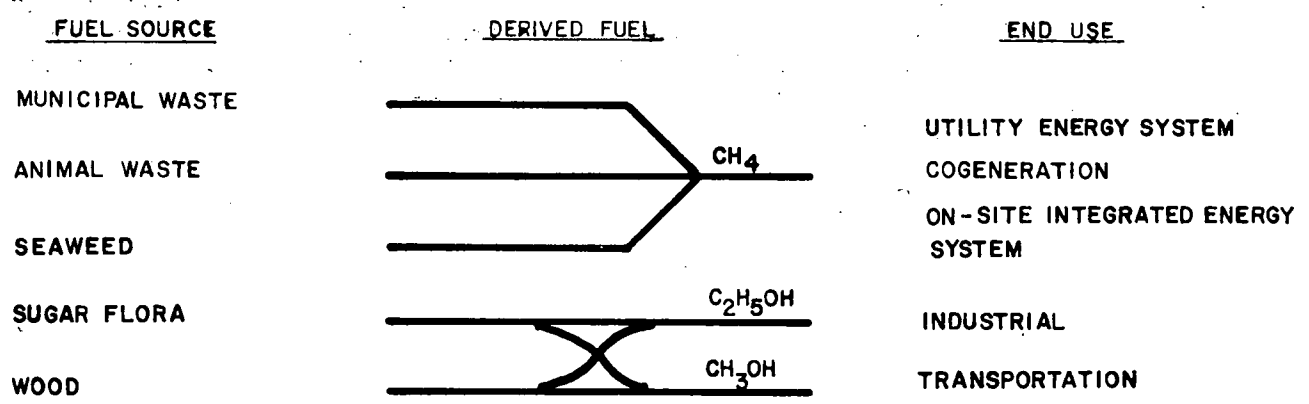


FIGURE 1 APPLICATION OF PHOSPHORIC ACID FUEL CELLS IN HAWAII FOR ENERGY SELF-SUFFICIENCY

The best fuel cell for all these fuels and applications, in terms of availability, is the phosphoric acid fuel cell. It is being developed for electric power and cogeneration applications in 5 to 10MW sizes by Westinghouse/Energy Research Corporation (W/ERC) and by United Technologies Corporation, and by the same organizations in the 40 to 120kW size range for on-site integrated energy systems (OS/IES). A fuel cell for transportation purposes for passenger cars would require about 15kW and for buses about 60kW. The W/ERC units use air-cooled fuel cell stacks whereas other manufacturers' technology is based on liquid cooled stacks.

The larger fuel cell can operate in an electric only mode at a 7500 to 9500 heat rate depending on fuel source. The OS/IES system can reach an overall efficiency of 80 to 90%, producing both electric and useful thermal energy.

The basic fuel cell system for virtually all applications will consist of: a fuel processor, most likely a steam reformer, to convert the methane or alcohol fuels into a hydrogen-rich gas; a phosphoric acid fuel stack to produce DC power; and a microprocessor for control purposes. Additional equipment, such as a DC to AC inverter about 95% efficient, is required in many applications but is not necessary for transportation systems where DC motor drives can be used. Some applications will use additional heat exchange equipment to recover fuel cell waste heat for heating and cooling purposes. In Hawaii waste heat will probably be used for either industrial purposes, water heating, or air conditioning. Integration of the fuel cell systems with solar systems may be beneficial.

In the paper, examples of a 120kW OS/IES system, a 7.5MW electric utility system and approaches to transportation systems within the framework of the Hawaiian economy, including its specific energy consumption in various sectors, will be discussed.

Because of the relatively high efficiency of fuel cell systems, savings in the amount of biomass fuel and in the capital investment for biomass processing equipment can be realized compared with end use in conventional electrical or mechanical energy generating equipment. A total system analysis must consider investment in land, biomass equipment and electrical generation equipment.

POWER CONDITIONING

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Many of the new means for electric power generation and storage are inherently dc, and even those which are not may be implemented with dc generation. To supply loads that are predominantly designed to utilize 60 Hz ac or to operate in parallel with a conventional utility distribution, the dc must be converted to 60 Hz of appropriate quality. Solid state power conditioning equipment is the vehicle for accomplishing this end.

The technology of dc to ac conversion is long established. We know that there are four basic types of switching power converter that may be used, and that their inherent characteristics are independent of the multitude of detail design variations that can exist for each. However, the specific problems attending power conversion for advanced energy technologies have not received adequate address. Most present day commercial power conditioning equipment is manufactured in small quantities and with performance specifications set by individual customer requirements. Although cost and efficiency are key factors in a competitive market, the limited market volume and relatively high engineering cost content of the equipment have inhibited efforts toward substantial cost reduction or efficiency maximization. In fact, the cost-efficienty trades are not well understood.

Power conditioning can help the new energy technologies succeed if it is low in cost, highly efficient and very reliable. These goals are probably attainable if the equipment's design and manufacture are properly addressed, despite the very dismal picture presented by currently available equipment. It is a common misconception that intensive study of the available options will lead to a new technology choice yielding lower cost, higher efficiency and greater reliability than are now common. Such is not the case; the technologies now in use are those which will serve the new applications. Cost reductions, efficiency improvements and reliability gains will come about as a result of developments in the following areas:

- Semiconductor switching devices - reduced costs due to increased production volume, and higher yields as process control improves. Reduced losses as device characteristics are improved by better materials and process control.

- Equipment manufacturing techniques - increased market volume will allow abandonment of hand-crafted, "job-shop", assemblies and exploitation of more efficient techniques with lower labor and overhead costs.

- Detailed design changes in equipment and components - designers will exploit switching device improvements to effect reductions in passive component costs and losses.

- Modularized designs - particularly for the lower power applications, below MW, the economies of higher production volume will be fully realized by having standardized power conditioning modules serve a range of applications, both as regards power level and source type.

It can be concluded that power conditioning equipment, an essential subsystem of advanced electrical energy systems, will not prove a hindrance to their exploitation. Development work is necessary to achieve the overall performance needed, but the basic technology exists and is well understood. Results will be obtained more rapidly if the real problems are addressed - searches for technological "breakthroughs" are not likely to be fruitful.

The author acknowledges the contributions of the Electric Power Research Institute, which provided the funding for one major study of the subject under the project management of Mr. James W. Beck, and of the Department of Energy, which has provided funding for several studies as parts of various contracts on system conceptual designs. Acknowledgement is also due the National Science Foundation, which provided funding for a conceptual design study on solar photovoltaic systems that included power conditioning evaluations.

ELECTRIC SYSTEM IMPACTS OF DISPERSED ENERGY TECHNOLOGIES

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Recent attention has been focused on the contribution to energy supplies by small-scale or decentralized energy technologies (DETs). These technologies are generally characterized by the use of renewable resources; by siting closer to the end user and away from large, central energy complexes; by higher efficiencies and more benign environmental effects. Examples of decentralized energy technologies include wind machines, solar space heating, small-scale hydro, cogeneration, and fuel cells. Decentralized energy technologies may partially or fully substitute for electric and nonelectric sources, may be interconnected or independent of a central delivery network, and may be owned and operated by individuals or communities. DETs are of interest principally because they offer the potential benefit of reduced dependence on fossil fuels, reduced capital requirements compared to large central facilities, and minimum environmental effects. The key concern is the compatibility of DETs with larger energy delivery systems, particularly where DETs would be interconnected with electric utility systems.

This paper focuses primarily on the special requirements and impacts of integrating DETs into electric power delivery systems, including their effects on generation, transmission and distribution system planning and operation and the determination of rates for energy exchanges between utilities and customers. Systems Control, Inc. (SCI) has been involved in several studies [1-5] ranging from developing assessment methods to detailed cost/benefit studies of the integration of DETs into future utility systems. The principal conclusions which have emerged from these studies will be discussed in this paper:

(1) Renewable resource technologies such as wind turbines and photovoltaic systems can provide an economic alternative to large-scale central generation if their projected cost goals can be met. Further, no overwhelming technical or institutional barriers have been identified which might prevent DETs from being integrated into future utility systems.

(2) Wind and solar resource characteristics are more important in determining the benefits of integrating these devices into utility systems than utility characteristics such as load shape, season of peak load and generation mix.

(3) Intermittent DET technologies such as wind and solar do contribute to the reliability of a power system, although this benefit decreases with increasing DET penetration. One kilowatt of intermittent generation would typically replace from 0.15 to 0.60 kilowatt of central-station conventional generation capacity. DETs have a negligible effect on improving the reliability of distribution systems.

(4) When a substantial number of DETs are integrated into a utility system the intermittent nature of DET energy production might increase the utility's requirements and cost for load following and system-spinning reserve. A more thorough evaluation of this issue should be undertaken to identify the key parameters and conditions under which

load-following and spinning-reserve capacities are adversely affected. More knowledge of short-term resource variations and device performance and the effects of spatial diversity would be required in such an investigation.

(5) Solar photovoltaic systems with dedicated storage devices are less economical from the view of the total system than photovoltaic systems without storage and with central storage devices operated by utilities.

(6) The potential for utility oil reduction is not as dramatic as one might expect. This result depends on the actual oil-fired generation still in use 15-20 years hence, and the fact that wind and solar installations tend to displace base-load rather than peaking capacity. For example, at one percent penetration of wind capacity for a typical EPRI synthetic utility, average oil savings were approximately 125,000 bbls/year for 100 MW of wind capacity.

(7) DETs are unlikely to offer significant distribution investment savings due to their undependability at the time of distribution system peak loads. Spatial diversity among dispersed wind generators may improve their capacity value at the bulk generation level, but for distribution systems this improvement is expected to be insignificant.

(8) Although small customer-owned DETs would not seriously disrupt present distribution protection coordination, two key technical issues need to be addressed. First, when sections of distribution systems containing DETs are isolated, DETs can potentially be self-excited and feed back to the grid, posing a safety hazard to utility line crews and other customer's equipment. Second, the cost of additional protection equipment required to maintain the safety and service quality standards may become an impediment to rapid commercialization of small, customer-owned DETs.

(9) There is a general lack of cost data on DET operation and maintenance since few installations exist. Scattered experience with small-scale energy sources indicates that operation and maintenance procedures must be carefully controlled to avoid expensive operating costs.

CONTRIBUTING AUTHORS

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PRE

THE INFLUENCE OF DISPERSED STORAGE AND GENERATION ON COMMUNICATION REQUIREMENTS FOR LOAD MANAGEMENT AND DISTRIBUTION AUTOMATION & CONTROL

Raymond K. Adams * and Thomas W. Reddoch **

A typical electric utility system today is an aggregate of cental station generating plants and loads, linked via a high voltage transmission and a low voltage distribution system in which the bulk system, the production and transmission, operate independently of specific distribution behavior. Historically, as the complexiety of the bulk system has increased, centralized control has become a necessity. The use of transmission SCADA sytems (Supervisory Control and Data Acquisition) in combination with generation control systems has led to an integrated central control for the bulk system. These systems pioneered much of the present communication practice for the electric utility industy. Presently much information is transmitted in digital form as bit serial data which is converted to bit-parallel word data for computer processing. Information collected at the central point in random order by simultaneously polling the remote facilities permits effective use of communication channel capacity. About every 1 to 2 seconds all remote points are sampled. Often data compaction is applied at the remotes, improving communication efficiency by only transmitting data which has changed since the last sample. The sampling rate for each type of information is determined by functional application, i.e., for load frequency control, economic dispatch, voltage regulation, security measures, etc. In addition to status monitoring and control applications, communication systems are a vital part of the protection system for bulk system operation. Microwave systems, powerline carrier systems, and some hard wire systems have been used for years for bulk power, transmission and substation oriented communications.

In the early 1970's when the real price of electricity began to increase, the electric utility industry began to consider altering the use patterns of electricity to allow greater efficiency of both facilities and capital by decreasing the ratio of peak to base load demand and the conservation of non-renewable fuel resources. Interest in load management and the associated distribution automation and control (LM&DAC) grew rapidly as the utilities began to actively pursue cost reduction and conservation programs. The communication needs of LM&DAC devices and systems were recognized early as a significant factor in the eventual success of LM&DAC applications. This recognition led to several manufacturer/utility pilot installations and to the joint DOE/EPRI Program[1] "Field Demonstrations of Communications Systems for Distribution Automation". Final reports of the five individual projects in that program are now in the editing and publication stages.

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It should be recognized that the load management function of interrogation of specific load behavior to influence central station operation is a significant departure from classical utility structure which has been moving toward centralized operation. Furthermore, this signals a further move toward vertical integration of utility operation and defines new communication needs. It seems likely that the difficulties and successes of communication systems used for LM&DAC will have a direct bearing on the communication systems that will be required for the much more complex tasks involved in vertically integrated system control. Several fundamental communication lessons are being learned in the joint DOE/EPRI tests and various utility pilot tests.[2] Briefly, these are that for distribution system two-way communication: (1) Powerline carrier (PLC) communication systems must be extremely well engineered to surmount distribution network noise and attenuation characteristics and communication pathway changes wrought by network reconfiguration. (2) Telephone communication systems offer superior signal propagation but the message and equipment tariffs are unknowable now, and as projected may be too high. (3) UHF radio communication systems will require significant engineering evolution and innovation to surmount problems of line-of-sight signal path vs. geographic terrain and signal attenuation due to tree canopy and structure effects. As often happens when a detailed look reveals difficult-to-solve problems, the DOE/EPRI field tests may result in a renewed interest in CATV or other co-axial cable communication methods involving orbiting satellites or combination broadcast radio/VHF signalling methods.

Distributed power production will represent further departure from classical utility structure. As it evolves, the distribution system will lose its unidirectional properties and this must be reflected in further assessment of communication needs. Information transfer will be required for system status and monitoring, especially will the status of the decentralized source be required for equipment protection, personnel safety, and the general quality of the electrical system. A study of the communication needs related to the functions and operating philosophy that seem likely to come with distributed storage and generation (DSG) suggests three charactistics that will impact their communications needs. These are: (1) The requirement for secure signalling channels to communicate DSG control and status signals, (2) The use of microcomputer-based local controllers that will provide status and alarm signalling and will fulfill nearly all the control needs of each distributed source, and (3) The significant new design and operation burden that will be placed on distribution system switching and system security equipment imposed by the two-way power flow.

The specific requirements of the communication system will be determined in part by the characteristics of the particular distributed source. For example, cogeneration electric production will be determined by the primary process operating characteristics. These characteristics will likely be orderly and predictable, and perhaps could be scheduled. In contrast small wind electric systems could be on intermittant or a short time scale basis and thus require more status information. Solar-electric systems tend to be more predictable with electric production determined by seasonal & diurnal characteristics except on days with broken clouds. Then in summary; the communication requirements of distributed sources are complex and will be determined by the influence of source characteristics on vital electric system processes.

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WIND INTEGRATION VIA VARIABLE SPEED

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To date, the concept of variable speed applied to AC power generation rather than utilization has not been widely exploited. A hindrance to such an application may be that the benefits of variable speed wind energy converters (WECs) are not well understood. This paper highlights important advantages in integrating a variable speed WEC within a power system.

In a recent study, alternative variable speed configurations were identified and rated according to their relative cost and performance [1]. Therein, it appears that a doubly-fed induction generator has significant cost advantages over other systems. Furthermore, this study indicates that either a cycloconverter or PWM force-commutated rectifier and inverter is most suitable for a variable speed WEC. Variable speed operation of a wind turbine generator would result in the following specific benefits:

1. Increased Output Under Light and Heavy Wind Conditions. Figure 1 represents a wind coefficient Cp vs. wind velocity which is typical for a MOD-2 wind turbine. WECs which operate in synchronism with the utility can be optimized at only one wind condition, for example point B on Fig. 1. Operation at light wind conditions (AB on Fig. 1) is obtained by reducing Cp and thereby the aerodynamic efficiency. Above rated wind velocity the efficiency is again cut, this time by blade angle control. The resulting power available from the wind as a function of speed is plotted in Fig. 2. When the generator speed is allowed to vary, the ratio of wind velocity to rotor speed can be maintained constant over a range of light wind conditions (Pt. A' on Fig. 3) thereby capturing increased wind power as shown in Fig. 2. Additional energy can also be captured by allowing the rotor speed to rise above synchronous under heavy wind conditions.

2. Elimination of Blade Control. The rating of the converter rises in direct proportion to the slip power. In general, blade angle control is still needed in order to limit the generated power to a fixed level above rated. However, it appears that continuous angle control is not a necessity and a simple switching between two blade angles is sufficient. Although normal control of blade angle is generally

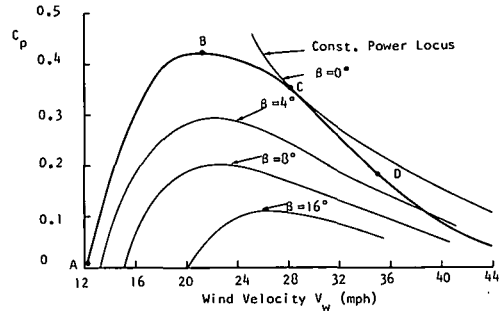


Fig. 1. C_p vs. Wind Velocity at Fixed Tip Speed (RPM)

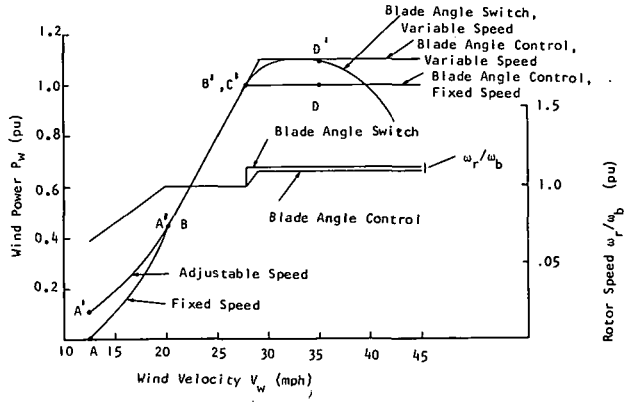


Fig. 2. Wind Output Power vs. Wind Velocity for Fixed and Adjustable Speed Operation

restricted to positive angles it can be noted from Fig. 3 that if the blade angle is switched to a negative value, Cp drops to zero as wind velocity increases corresponding to an aerodynamic stall condition. Figures 2 and 3 show how a switch from point B' to C' sets the blade angle in a condition which produces almost rated power over a range of wind speeds. The power then drops to zero for very large wind speeds. The rotor speed is self limiting thereby preventing a runaway condition.

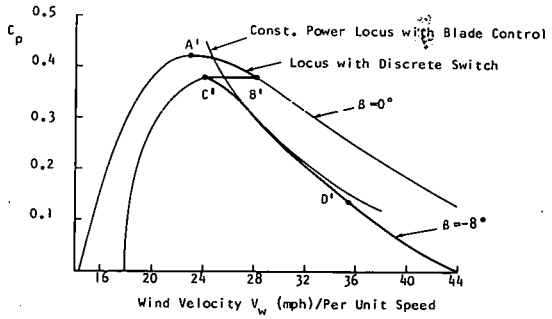


Fig. 3. C_p vs. Wind Velocity/Tip Speed Ratio for Adjustable Speed Operation

3. Rapid Recovery from a Fault Condition. The most frequent electrical disturbance is a line fault. Unfortunately, faults in a WEC system are complicated by the nature of the prime mover. Compliance in the quill shaft results in an angular twist under loaded conditions which, when referred to the machine angle through the gear ratio, corresponds to a large electrical angle. Rotor swings of several hundred degrees can occur under fault conditions making the consequent reclosing operation extremely difficult [2]. Operation of the generator under variable speed opens up the possibility of reclosing immediately after the fault has been cleared even if the rotor is not near synchronous speed.

4. Strong Electrical Damping. Large wind generators typically possess numerous lightly damped mechanical modes. Fast response pitch control in the MOD-1 and -2 systems are highly effective in reducing torsional oscillations in the "High Mode" of operation. However, the blade control becomes inactive during the "Low Mode" (light wind conditions). Oscillations could rise to substantial values during this mode. Although the long term effect of these oscillations has yet to be determined it is clearly beneficial to reduce these oscillations to a minimum. The rapid speed of response inherently present in a variable speed configuration could be put to valuable use in damping these oscillations. Since the converter is continuously active, damping can be achieved over all wind conditions.

5. Reduced Power Fluctuations. The prime mover torque of a wind generator is essentially a random variable. When the generator is tied synchronously to a power grid this random power input is transmitted through the mechanical system and ultimately appears as a random power fluctuation at the machine terminals. A coincidence of such power swings in several generators in a wind farm could cause excessive voltage swings in adjacent distribution networks. However, if generator speed were allowed to change, the random nature of the wind could be absorbed in accelerating and decelerating the wind turbine, thereby keeping the electrical power relatively constant. Power swings in wind farms would, to a significant extent, tend to be smoothed out.

6. Power Factor Adjustment. A double-fed induction generator resembles a conventional synchronous machine in many respects and the major benefits of this machine are not sacrificed. Most importantly, the power factor supplied to the power grid can be adjusted over wide limits (lead or lag). Power factor adjustment is available over the entire speed range of the doubly-fed machine.

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RRE

INTERCONNECTING AC AND DC SYSTEMS

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Around 1900 the early all-dc power system concept gave way to the all-ac power network with the development of the polyphase ac system and the transformer. The 1930's saw a renewed interest in the dc interconnection and in 1954 commercial high voltage dc (HVdc) transmission made its debut in Sweden. Since then, 20 additional HVdc transmission interconnections have gone into service worldwide, and several more are under construction or in the planning stages. The basic motivation for HVdc links for bulk power transmission, in otherwise all-ac networks, is economics.

DC can cost less than AC for Long Distances. The Pacific Intertie (1362 km), and similar existing lines were justified because ac transmission alternatives considered at that time would have been more costly. Very long ac interconnections (650 km and up) require multiple circuits, with substantial amounts of series capacitor compensation and/or shunt reactive compensation, in order to ensure stability and reliability of the all-ac intertie.

DC versus AC for Submarine Cables. A decided advantage is enjoyed by the high power dc interconnection when submarine cables are required for distances greater than about 60 km. Here again the advantage is one of economics because several low voltage ac cables would be required to transmit the same power of a commercially available dc cable.

DC versus AC for Underground Transmission. Similar economic arguments can be cited for underground dc cable feeds into high density urban centers. The shortage of rights-of-way for high power overhead transmission into the urban load areas is causing great interest in the advancement of cable technology and compact substation designs.

Asynchronous Connections Between AC Systems. The back-to-back ac/dc/ac converter with no intervening distance is characteristic of four in-service interconnections and three more under construction. When such interconnections are used between two systems of the same power frequency, the choice is made over ac because numerous high voltage ac lines would have been required to provide a stable ac interconnection. High power interconnections between systems of differing power frequencies (60 and 50 Hertz for example) can be more economical with a back-to-back dc tie than with an electromechanical frequency changer.

Renewable Energy Resources and AC/DC interconnections. HVDC transmission is already playing an important role in exploiting a very old renewable energy resource - hydro power. The Pacific Intertie, connecting northern Oregon with Southern California, is a good example of this application. That line transports 1440 MW (soon to be uprated) of hydro-generated-power from the Pacific Northwest to the densely populated Pacific Southwest. Similarly, the Nelson River HVdc system transmits hydro-electric energy from Northern Manitoba to southern Canada and the United States over a distance of about 900 km.

Some of the new renewable energy resources not previously incorporated into the electric power system, such as photovoltaic and fuel cells which are dc sources, and variable frequency sources like certain wind and small hydro systems, will require ac/dc conversion to be compatible with modern constant frequency ac systems. Because of their small ratings, most of these new sources are expected to be integrated into the distribution (low voltage) systems. However, the largest of these sources may be compatible with high voltage networks and even some of the smaller sources might connect into future multiterminal HVdc systems through series connected dc terminals.

Some Ocean Thermal (OTEC) generation plants, while they generate ac power, may require ac/dc conversion where off-shore distances are great requiring dc submarine cables for connection to the ac system. OTEC plants, therefore, may interconnect conveniently with HVac systems through HVdc links.

Multiterminal HVdc - State of the Art. All HVdc systems now in service operate normally as two-terminal systems. Future bulk power systems will include multiterminal HVdc networks embedded in the ac system. The potential benefits of such a configuration are under consideration for the western U.S. interconnection, whereby remote sources of fossil fuels and hydro resources would be integrated via a multiterminal dc/ac network to serve the widely separated load centers on that sprawling power system. Multiterminal HVdc also promises a degree of economic power routing control unparalleled in an all-ac system. Research projects sponsored by the utility industry, the Electric Power Research Institute (EPRI) and DOE, which are pushing the frontiers of multiterminal HVdc controls, HVdc circuit breakers, and compact HVdc and ac substation designs, will expedite the realization of the truly integrated ac/dc interconnection.

HVdc Interconnections Between the Hawaiian Islands. A multiterminal HVdc network connecting the otherwise separate Hawaiian Island electric systems is technically feasible. Providing the economic incentives are sufficient, certain renewable energy sources (particularly OTEC) which require dc/ac interconnections to the ac grid could be made on integral part of the multiterminal network. Such an HVdc network would bring the benefits of system interconnections to the otherwise isolated ac systems. Planning ac/dc interconnections requires special consideration of reactive power supplies to support ac/dc converter operation, and harmonic filters to minimize voltage distortion and the induction of noise in adjacent communication circuits. These planning considerations are mature and improving steadily as the incentives for ac/dc systems grow in today's energy conscious world.

PRE

HAWAII SPECIFIC PROBLEMS - DEEPWATER DC CABLE TRANSMISSION

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The concept of energy self-sufficiency is one of Hawaii's major goals. Toward this goal, each of the State's four counties have developed energy self-sufficiency plans that are being translated into functional plans. These functional plans will be submitted to the State Legislature and coordinated into an overall, or State-wide, regional development plan. One of the principal purposes of the self-sufficiency plans is to identify alternate and renewable energy sources on each island and develop plans for implementing the use of those energy sources.

A key element in the future development and commercialization of the State's alternate or renewable energy sources will be the ability to transmit power from one island to another. At present this ability does not exist. To develop this ability, Hawaiian Electric Co., in association with Parsons Hawaii, Hawaii Natural Energy Institute, Hawaii Institute of Geophysics, Simplex Wire and Cable Co., Hawaiian Dredging and Construction Co. and the State Department of Planning and Economic Development, submitted a proposal, in June 1980, to the Department of Energy for a deepwater DC transmission cable demonstration program. The program has been designed to determine Hawaii's specific problems with DC cable transmission, and to develop cost-effective solutions to those problems. The program consists of four work phases and will be conducted over a 3-1/2 to 4-year period.

At present it is known that the ultimate inter-island cable system will be deployed over greater distances and at greater depths than presently deployed or planned submarine cable installations. The longest cable link in Hawaii will be approximately 240 km, between the Big Island of Hawaii and Oahu, the primary electrical power market demand. A portion of the cable length will be deployed at depths over 2,100 m. The majority of the Hawaii cable system will be deployed at depths between 900 and 1,000 m. The longest and deepest power transmission cables deployed to date are the Skagerrak Cables between Denmark and Norway. These cables are approximately 130 km long and deployed at a maximum depth of 550 m. The distances and depths that the Hawaii cables will be deployed will introduce unprecedented structural and mechanical stresses on the cable during deployment operations and introduce retrieval, repair and redeployment problems that will require a new generation of cable handling equipment and procedures.

Figure 1 indicates the probable inter-island cable routing and Table 1 indicates the distances and depths between the major Hawaiian islands. The routes and depths are to be confirmed through detailed route surveys and oceanographic investigations. The cable to be utilized (Figure 2) will be a single conductor, ± 250 KVDC, impregnated jute, lead sheathed, contrahelical torque balanced type cable that will be an extension of present knowledge gained from the Skagerrak Cable and OTEC riser and bottom cable studies that have been sponsored by DOE. An extensive series of mechanical, structural and electrical tests will be conducted on the cable and on a repair splice that is to be developed during the demonstration program. Also, extensive cable ship and handling equipment surveys, studies and design programs will be conducted during the performance of the demonstration program.

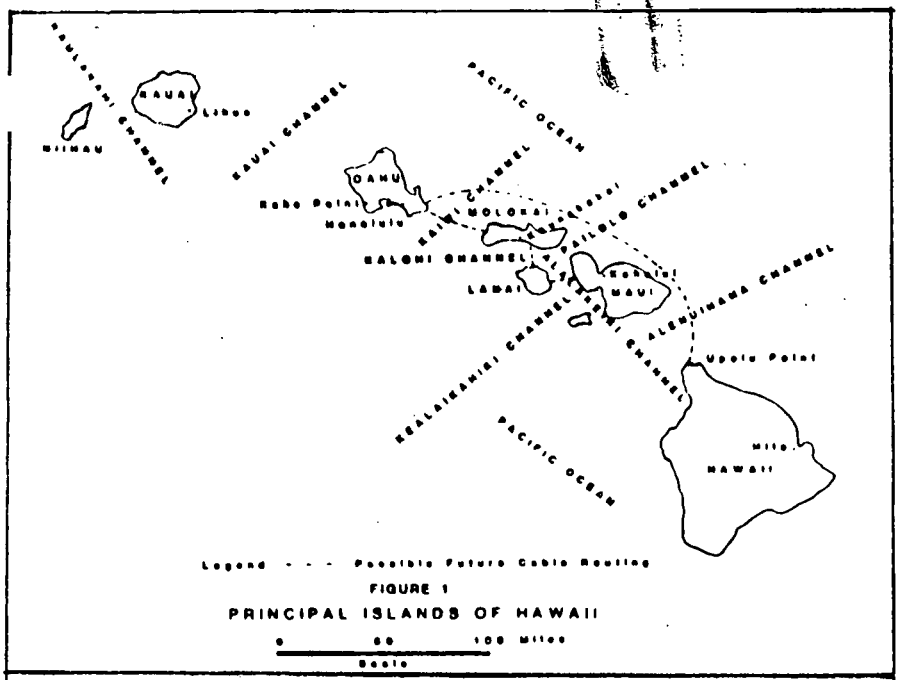


FIGURE 1
PRINCIPAL ISLANDS OF HAWAII

Table 1 Depth & Length of Channels Separating Islands

Islands	Channel	Approx. Depth	Est. Length
Oahu-Molokai	Kaiwi	670 m	40 km
Maui-Molokai	Pailolo	256 m	15 km
Lanai-Maui	Auau	66 m	16 km
Maui-Hawaii	Alenuihaha	2,100 m	56 km
Oahu-Hawaii	Open Ocean	Avg. 900 m	240 km

The ultimate goal of the program will be to develop a commercial cable criteria document that can be issued by private or public agencies to cable manufacturers and installers as a performance specification document.

Presently known problems specifically relating to a Hawaiian inter-island deep-water DC cable system are the unprecedented depths and distances at which the cable will be deployed. It has been estimated that during deployment of the cable in the 2,100 m deep trench between Hawaii and Maui, the static weight of cable suspended from the cable ship will be approximately 55,481 kg. This weight will require special cable handling equipment designed to maintain constant tension while paying out the cable at a predetermined speed.

The distances to be covered also present unprecedented problems in cable handling. Due to the contrahelical torque balanced armoring, the cable reel must rotate, rather than cable being rotated around a stationary reel. The weight of the cable alone, estimated to be 34.2 kg/m in air, will require an extremely large turntable type reel and cable ship. These and other problems will be investigated during the conduct of the proposed demonstration program. All problems appear to be solvable and in many instances, will represent an extension of present state-of-the-art knowledge. Solutions to the problems, will be applicable to other areas, such as OTEC platform transmission cables and the intertying of other island communities. The development of the capabilities to intertie the Hawaiian Islands will allow governmental and private agencies to plan and develop our alternate and renewable energy sources on a truly regional basis.

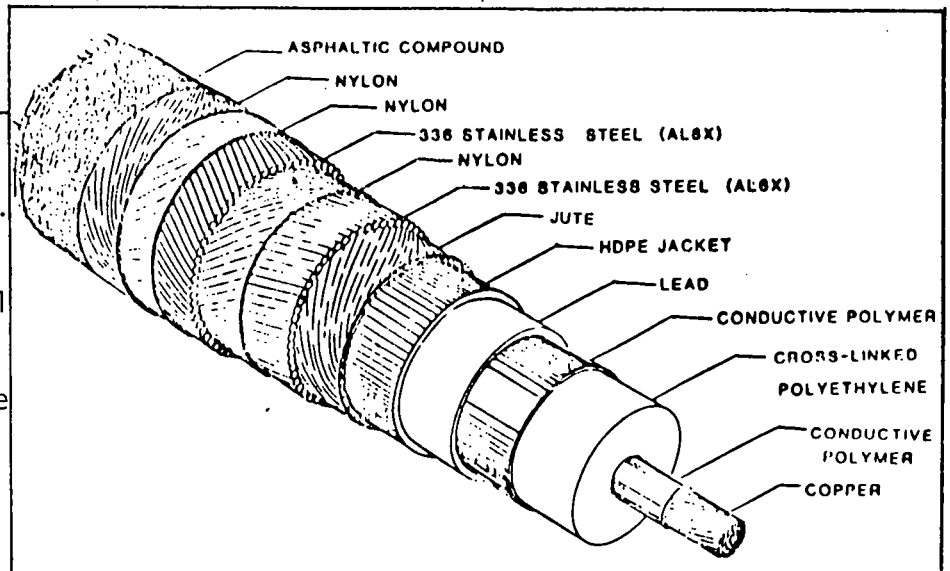


FIGURE 8. REPRESENTATIVE HVDC CABLE DESIGN FOR HAWAII

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INTEGRATED DESIGN AND TESTING OF OTEC RISER CABLES

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Simplex Wire and Cable Company
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Six candidate designs have been developed for riser cables capable of conveying the 3-phase, 60-hertz, 138 kV, output of a 100-megawatt OTEC power plant. Of these six designs, two were selected for manufacture of full-scale test specimens being used in service simulation tests presently underway. Testing of key cable component materials, and backups, is also underway. The results of all tests will be used as necessary to modify existing riser cable designs to ensure trouble-free operation of OTEC riser cables for the duration of a 30-year deployment period.

The cables being manufactured for testing include a self-contained oil filled (SCOF) cable with 1250 kc mil copper keystone conductor, and an extruded cross-linked polyethylene (XLP) cable with concentric 350 kc mil copper conductor. Both cables are torque-balanced, externally armored with a special austenitic stainless steel alloy (AL-6X), and have low-copper arsenical lead sheathing. Figure 1 details construction of the XLP dielectric cable. The specified designs take maximum advantage of proven high voltage cable materials, and the dual choice of XLP and SCOF cables allows concurrent testing and evaluation of the two most promising riser cable dielectrics.

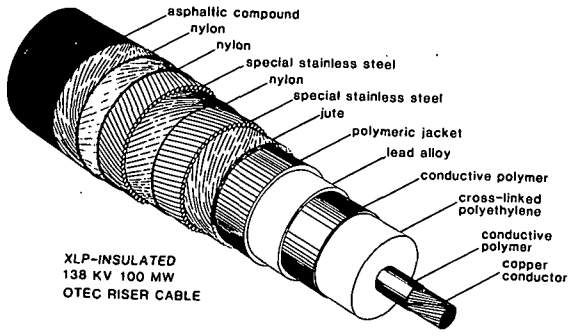
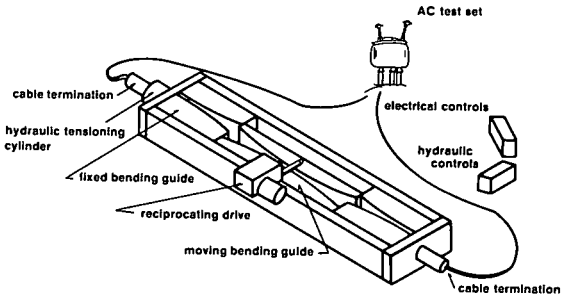


FIGURE 1

The riser cable testing program is designed to simulate service conditions anticipated during a 30-year design life. During service, the cables will be in water from 4000 to 6000 feet deep and will be subjected to millions of cycles of flexure, tension, and torsional movement due to platform and wave motion. These motions may cause fatigue in cable components. In addition, the riser cables will be subjected to thermal effects due to electrical load and simultaneous exposure to high electrical stress in the dielectric.

The testing program includes both component and full-scale electro-mechanical testing processes. Component tests being undertaken include coupon fatigue, high-cycle bending, and low-cycle bending tests on sheathing candidates, plus corrosion fatigue tests on armor wire materials. Tension-elongation tests on both core and full-size cable are being conducted. Pressure tests, to simulate deep-sea service conditions; bending stiffness tests, to provide data essential to bending fatigue tests of hermetic sheaths; crush tests, to simulate sidewall pressures on the cable during laying operations; and suspension tests to verify integrity of cable construction in long vertical drops are also being conducted on the full-size test cables.

The testing program is highlighted by the conduct of tests simulating the combined electrical and mechanical stresses occurring on riser cables in the ocean environment. These electrical/mechanical (E/M) fatigue tests, presently underway, are performed on full-scale test cables using an electrical/mechanical fatigue machine (Figure 2). The machine was specially designed and built by Simplex to provide simulated OTEC riser cable service conditions, including simultaneous cyclic tension, cyclic bending, voltage stress, and conductor operating temperature in a seawater environment. A ten-year simulation test provides approximately 2,000,000 cycles of bending and 110,000 cycles of axial tension (ranging from 56,000 to 139,000 pounds) in a 21-day period. Further tests will be conducted on separate cable samples to simulate 20, 30, and 50-year service periods.



ELECTRICAL/MECHANICAL FATIGUE MACHINE LAYOUT

FIGURE 2

During the E/M tests, the conductor is energized at 96 kV with 60-cycle AC power, with amperages selected to bring the cable to a thermal condition similar to that which will exist in service. Dissipation factor/capacitance measurements at line to ground voltage levels of 80, 96, 120, and 160 kV are made at specified intervals during the test. For the solid dielectric cable (Figure 1) partial discharge sampling measurements are also taken at 80, 90, 120, and 160 kV. Following test completion, switching impulse, 60 Hz withstand and 60 Hz breakdown tests are conducted. Dissection and visual examination of the cable also take place at test completion.

Favorable performance of the cables and components during the testing program serves to increase confidence that the test riser cables can be successfully applied to OTEC service. Failure of either cable or components during testing indicates the need for reanalysis of cable design and materials. Backup sheath and armor materials are being tested and the results of these tests can be used in specification of alternative cable constructions if necessary. This integrated program is designed to result in having riser cable available in final manufactured form for use with an OTEC pilot plant, presently scheduled for 1985 deployment.

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BOTTOM CABLES

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Industrie Pirelli S.p.A.
Milan, Italy

An off-shore nuclear or OTEC floating power plant is electrically linked to the mainland by submarine cables. "Riser cables" move from the plant down to the sea bottom, and "bottom cables" connect the bottom end of the riser cables to the mainland.

The characteristics of bottom cables obviously depend on the electrical features of the power plant, on the length and depth of laying, on the properties of the sea bottom soil, etc. A feasibility study was recently carried out for DOE, with reference to their OTEC Project. DOE chose a number of representative sites, namely some sites far from mainland (in the Gulf of Mexico, distances between 80 and 150 miles) and some sites only few miles from important islands (Puerto Rico, Hawaii). The power to be transmitted was assumed 400 MW, but in the case of islands cables suitable to plants producing 100 MW had also to be studied. In all cases the water depth at the plant site was assumed to be 4000 ft (in one case 6000 ft), i.e. largely greater than the maximum laying depths (1700 ft) so far met by submarine power cables. Moreover, cable embedment of 8 ft was required in water depths of 300 ft or less, to prevent external mechanical damages.

To transmit 400 MW on long distances, DC cables at $\pm$ 250 kV must be used; when distances of few miles only are involved, i.e. for plants close to islands, 345 kV AC cables are instead necessary. In the second case, AC cables at 138 kV can be adopted if 100 MW only must be transmitted. All these links are carried out with one cable circuit only, which is (whenever possible) the more convenient solution.

Single core cables of the conventional paper impregnated type, with 1400 kcmil copper conductor cross section are the best solution for very long DC transmission of 400 MW at $\pm$ 250 kV. Similarly, the best solution to transmit 400 MW at 345 kV AC on relatively short distances consists of single core cables of the self-contained oil-filled type, with 1400 kcmil copper conductor cross section. In this second case, however, the possibility of an alternative solution based on cross-linked polyethylene must be borne in mind, because in this field an important research work (sponsored by EPRI and DOE) is at present in progress in USA. At least, single-core cables of the self contained oil-filled type are again the best solution for the transmission of 100 MW at 138 kV AC on short distances: the relevant copper conductor cross section is 440 kcmil. In this case an alternative solution consists of single core ethylene propylene rubber insulated cables, with 1250 kcmil copper conductor cross section. As usual for submarine cable links, in each case a spare cable is contemplated: it follows that cables are (2+1) for DC transmissions and (3+1) for AC transmissions.

For the above mentioned bottom cables the main technical problems are related to the exceptional laying depths. In the feasibility study carried out for DOE it

was assumed that the necessary mechanical strength and antitwist properties of the cables are achieved by means of a suitable construction of the conductor and the armouring consisting of two layers of galvanized steel flat wires with high tensile strength. The actual cable construction details, however, can only be defined through a careful experimentation.

Also important is the problem of flexible joints, which especially applies to the case of long links. Obviously, the cables must be manufactured in the longest possible lengths, thus reducing the number of joints which - even if flexible and manufactured according to the most advanced techniques - are potentially weak points. With reference to the sites chosen by DOE for the longest links, the sea bottom profile is such that it is not necessary to lay flexible joints at depths greater than 1700 ft provided the cable manufacturing and spare lengths are not shorter than 13 nautical miles. The present state of the art can meet the requirements concerning these minimum lengths, as well as manufacture and lay at the mentioned depth flexible joints of large cables at very high voltages.

Coming now to the laying and embedding problems, one must consider that to lay power cables with 5" diameter and 35 lbs/ft weight in waters 4000 ft or more deep involves the use of pulley diameters twice the present ones and braking forces between two and three times those met up to now. It follows that a new laying machine must be developed. The problem of embedding cables in shallow waters is more an economic than a technical one, and becomes important when long cable lengths must be embedded. As a matter of fact, different techniques are available to embed power cables in shallow waters, but they are expensive and time consuming. The state of the art will improve in future, because important works are being carried out in different Countries in order to develop more advanced solutions.

In conclusion, bottom cables for nuclear or OTEC power plants appear feasible, but important experimental work is necessary to define the construction details of cables and laying machine, the technology of recovery and repair operations (for which flexible joints are again necessary), etc. At the end of such work, suitable sea trials are advisable. It is worth mentioning that for the Hawaiian Islands bottom cables can be of outstanding interest if links between islands become necessary.

Problems and solutions previously mentioned are carefully dealt with in the final report of the OTEC Project feasibility study "Phase I: Selection of Most Promising Cables for Various Plant Representative Sites", carried out under contract EG-77-C-05-5360 (Bottom Segment Design). This final report is at present being printed by DOE.

PRB

COMPACT TERMINAL EQUIPMENT

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Historically, terminal design and construction offered few problems. Economic sites with adequate areas were available so "size" was not a significant factor. Equipment manufacturers were not faced with the challenges of compactness. Equipment support structures, bus supports and transmission lines used repetitive designs; little consideration was given to height or visual impact. They were primarily steel lattice construction, aluminum or wood. Voltage levels at that time permitted these luxuries. However, with the introduction of higher voltages (EHV and UHV), new criteria became necessary. In addition, land required for terminal sites, especially in urban areas, was becoming scarce and, where available, quite expensive.

Environmental restrictions soon began to dictate design criteria. More attention was being given to equipment compactness, as well as reduced, but adequate, clearances and overall height. "Inconspicuous" became the ideal; however, economics still maintained a high priority. This offered the design engineer a great challenge.

A thrust of the overview paper by Messrs. Klein and Smith is the role of dispersed storage and generation (DSG).

Smaller, or more compact, generation units naturally lead to compact terminal equipment and design criteria. To meet the parameters of compactness, manufacturers are recognizing the need for smaller, more reliable equipment. Reduced clearances have been proven, and gas-insulated equipment and complete substations are accepted more readily. Rapid development and availability at higher voltages has made gas-insulated equipment a significant contributor to compactness.

Presently, 765 and 500 kV class SF_6 equipment is available and is being installed in the United States. Numerous lower voltage, gas-insulated substations are in operation with future installations scheduled.

With new technology and the increasing use of new designs, there is a constant need for problem-solving and research to ensure the full potential of these innovations. With the support of various research groups in the design, study, testing and application of compact equipment and facilities, new advantages of this technology are continually being discovered.

This paper reviews the technological advances associated with terminal compactness over the past several years. These advances include reduced air clearances, SF_6 application, and HVdc, which are providing environmentally acceptable transmission and distribution facilities.

SECTION 11

ENERGY STORAGE SYSTEMS

ENERGY STORAGE SYSTEMS

Program Chairman: *D. D. Wyatt,* National Research Council
DOE Advisor: *Richard Jones*
Overview Presentation: Wednesday, December 10, 11:00 A.M.

"Energy Storage and Renewable Systems" 2-49
George F. Pezdirtz, DOE

SESSION I: Tuesday A.M.
Storage of Electricity

"Storage: Strategic Element in Energy Management" 11-1
Thomas R. Schneider, Electric Power Research Institute
"Design of an Adiabatic Compressed Air Storage Plant" 11-3
Michael J. Hobson, Acres American Incorporated
"Zinc/Chloride Energy-Storage Systems" 11-5
John W. Rowan, Gulf+Western Industries, Inc.
"Customer Owned Storage—The Potential for Battery Storage in Industry" 11-7
F. Jere Bates, J. C. Clifford, M. L. Duchi, T. R. Martineau, and J. C. Skelton, Battelle-Columbus
"Battery Requirements for Solar Photovoltaic Systems" 11-9
Robert P. Clark, Sandia National Laboratories
"Batteries for Solar Systems in Developing Countries and Rural Areas" 11-11
Paul A. Nelson, Argonne National Laboratory

SESSION II: Tuesday P.M.
Thermal Storage

"Solar Related Flywheel Systems" 11-13
Philip O. Jarvinen, Massachusetts Institute of Technology
"A Survey of Building Heating/Cooling Storage" 11-15
James F. Martin, Oak Ridge National Laboratory
"Thermal Energy Storage Systems for the Pulp and Paper Industry" 11-17
Howard Edde, Howard Edde, Inc., *Marshall W. Dietrich,* NASA-Lewis Research Center, *Erik Snellman and Harry Norden,* Snellman Engineering Co.
"Development and Demonstration of Aquifer Thermal Energy Storage" 11-19
James E. Minor, Pacific Northwest Laboratory
"Legal, Regulatory, and Institutional Considerations for Aquifer Thermal Energy Storage" 11-21
John F. Spencer, State of Washington Department of Ecology
"Molten Salt Storage Technology Development" 11-23
Robert W. Carling, Sandia National Laboratories

SESSION III: Wednesday A.M.
Storage for Transportation; Hydrogen; General

"Overview and Test Results of the Department of Energy's Electric Vehicle Battery Program" 11-25
William H. Webster, Department of Energy
"Sodium/Sulfur Batteries for Railroad and Delivery Vehicles" ..... *
Robert McAlvey, III
"Potholes and Pitfalls: The Road to Automotive Design" 11-27
Ida R. Hoos, University of California at Berkeley

*Abstract not available for printing in Conference Proceedings

Session III (continued)

"The GA Sulfur-Iodine Water-Splitting Process – A Status Report" 11-29
G. E. Besenbruch, H. D. Chiger, K. H. McConkle, J. H. Norman, J. S. Rode, J. R. Schuster, and P. W. Trester, General Atomics Company

"Solid Polymer Electrolyte Water Electrolysis Hydrogen Generation and Its Role in Renewable Energy Technology" 11-32
John H. Russell, General Electric Company

PRE

STORAGE: STRATEGIC ELEMENT IN ENERGY MANAGEMENT

Thomas R. Schneider
Electric Power Research Institute
Palo Alto, California

It is now national policy to reduce the consumption of oil in the United States and electric utilities are working to respond to the challenge. While the current option is energy conservation and increased use of coal and nuclear, new and renewable sources will be used to the extent feasible. Energy storage can be a key element in the strategy for shifting energy consumption from oil to coal and nuclear now and to renewable resources as they become available. This shifting of resource base clearly applies to the electric utility, heating and transportation market segments.

Energy storage is most economic when used to store the least expensive energy available and displace, or reduce, the use of the most expensive energy. It is the availability of low-cost off-peak (night) energy that makes the concept of energy storage attractive and economically feasible. Supplying peak loads with stored baseload power will help utilities respond to the national policy of conserving oil in particular, and conserving energy in general.

As an alternative to managing energy supply through storage, electric utilities today are actively pursuing load management by end-use storage to improve system load factors and reduce peak demand growth. This will reduce to some extent the need for peaking and load following generation units. However, recent studies show that even the extensive implementation of load management and end-use storage will not eliminate the type of flexible generating units best represented by today's pumped hydro and tomorrow's advanced storage technologies. For example, electric utilities today can plan for introduction of compressed air storage or underground pumped hydro (both having more flexible siting possibilities than conventional pumped storage) in their operating systems. The world's first compressed air storage plant has been in operation in Huntorf, West Germany, since December 1978, and engineering design studies of equipment suitable for U. S. utility use have now been completed by Middle South Services and the Potomac Electric Power Company. Sufficient engineering detail is now available to assure that no insurmountable problems remain for either compressed air storage or underground pumped hydro.

The introduction of more advanced energy storage technologies, such as battery systems, will depend greatly upon the success of ongoing research, development and engineering efforts. The next several years should resolve the basic question regarding the technical and economic potential of several battery concepts for both electric vehicle and utility applications.

The adoption of end-use storage, both as a buffer for the on-site supply of solar devised thermal energy and for the increased use of low-cost off-peak electric energy is now underway. Many, if not all, of the need for end-use thermal energy storage for heating and cooling applications can be met today with the use of rather conventional (at least non-exotic) technologies based on the storage of sensible heat in water or rock, or based on the phase change from water to ice. Development of more sophisticated approaches, using less familiar fluids or phase change materials, does offer some premise of reduced volume and different temperature-

heat transfer characteristics. Many concepts are being pursued and some are certain to find commercial applications.

Overall, energy storage can play a significant role in today's energy system and will play an even more significant role tomorrow. Renewable energy resources are not radically different in their characteristics from sources currently in use. Hydroelectric and geothermal are already used today in the generation of electric energy and are two of the most economic forms of generation available. Wind, photovoltaics and solar-thermal systems can be effectively integrated into today's electric systems whether operated as power sources on the utility side of the meter, or as "cogeneration" systems by the end-user. Being fundamentally intermittent sources, a reliable supply of power from this system will require alternative, back-up sources. This back-up power can be effectively provided through storage.

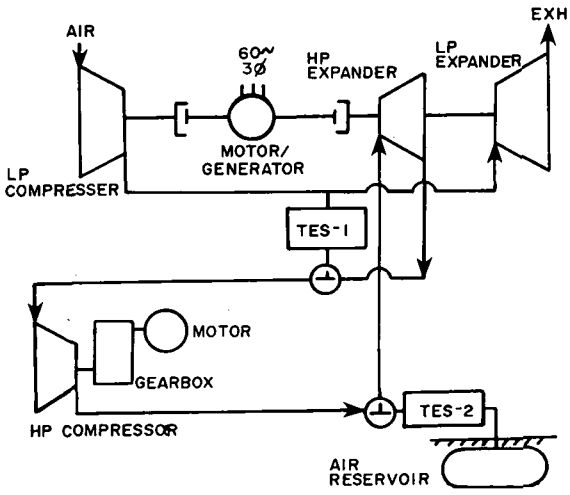
PRE

DESIGN OF AN ADIABATIC COMPRESSED AIR STORAGE PLANT

Michael J. Hobson, P.E.
Acres American Incorporated
Columbia, Maryland, U.S.A.

This paper presents the results of a conceptual design and engineering study of an adiabatic compressed air energy storage (CAES) system utilizing underground containment for thermal storage and water-compensated hard rock caverns for high pressure air storage. The study was commissioned by Battelle PNL of Richland, Washington. The adiabatic CAES concept, which requires no addition of fuel for firing into or heating of the turbine fluid, involves the integration of thermal energy storage (TES) with a conventional CAES plant. During the charging or compression mode, the heat of compression is stored in the TES system at temperatures of up to 870°F, instead of being rejected as waste energy in the case of conventional CAES design. The stored heat-energy is then used to raise the temperature of air as it leaves the storage enroute to the turbines during the power generation mode. Figure 1 shows the cycle in diagrammatic form.

FIGURE 1 Adiabatic CAES Cycle



The system is based upon the 1000-MW conventional CAES plant design prepared by Acres American for Potomac Electric Power Company (PEPCO), during the course of a pilot design project funded by DOE, EPRI and PEPCO. Common project features are the site in Maryland, the number of plant units and the ten hour design storage capacity. Three key areas requiring specific engineering development for the adiabatic system were: the design of large scale thermal storage systems, the transport and containment of large volumes of high pressure, high temperature air, and the selection of compressors and expander designs which could operate under the required conditions.

Thermal Energy Storage

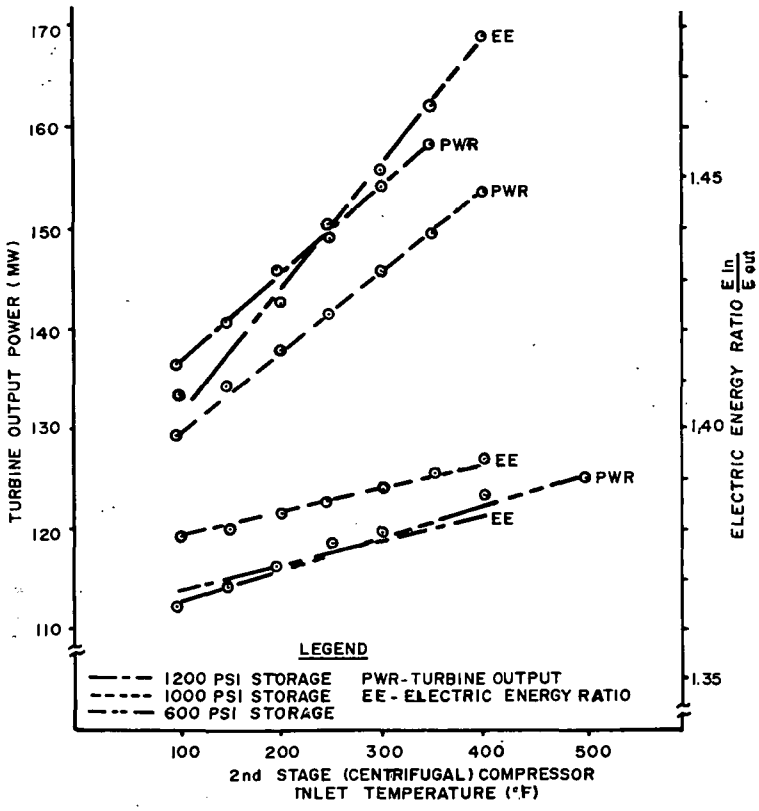
Investigation of TES systems indicated that a direct contact, sensible heat pebble bed system is the most practical heat store concept for air temperatures up to 900°F. The study focused on underground containment for the TES regenerators. The final design consists of several parallel, insulated steel cyclinder silos containing iron ore pellets and located in a cavern. Compressed air is distributed by ductwork, and controlled ventilation maintains cavern wall rock temperatures within acceptable thermal stress limits.

Compressor/Expander Matching

Maximum discharge temperatures of approximately 870°F are feasible with modification of existing industrial compressors available from Dresser Industries of Olean, N.Y. However, to achieve these temperatures at the large air flows required in CAES, multiple compressors must be arranged in parallel and in series. This results in complicated, multi-speed trains. The high pressure expander is difficult to design due to the relatively low volumetric flow which results in reduced efficiency from blade

tip losses. For this reason, the ratio of charging to generation air flow was modified from 1:1 to 1:1.2, which increases expander air flow and improves the efficiency.

FIGURE 2 ACAES Cycle Performance For Varied Storage Pressures



Other design problems such as maintaining rock temperature below specified limits and accommodating the considerable air pipe expansion were addressed during the study. The solutions to these problems will be discussed in the presentation together with the plant capital cost estimate and how it compares with competing energy storage concepts.

The thermodynamic cycle selection was based on a parametric analysis to maximize the turn-around efficiency of the plant. Industrial compressor and expander performance data were applied to mathematical models of large pebble bed TES systems. Pressure and temperature profiles for all components were calculated and utilized as input to Acres CAES Simulation Program. The results of the analysis showed that a two stage compressor and expander configuration could operate at an overall efficiency of 72 percent with maximum temperatures of 870°F and an air storage pressure of 1200 psia, provided that a trim cooler was incorporated to balance operation. Figure 2 shows some of the analysis results.

Maximum plant efficiency year-round can be achieved by maintaining the compressor atmospheric air inlet at 90°F. A proportion of the heat rejected in the trim cooler can be diverted to an air inlet heat exchanger for maintaining this temperature. Table 1 shows the results of the cycle performance analysis.

TABLE 1 - Unit Performance Data

	LP Set	HP Set
Compressor Power, MW	132	105
Discharge Temp, °F	877	830
" Pressure, psia	226	1215
Flow Rate, lbs/sec	650	650
Expander Output, MW	125	80
Inlet Temp, °F	865	825
" Pressure, psia	225	1125
Flow Rate, lbs/sec	780	780
Efficiency, % $\frac{\text{output kwh}}{\text{input kwh}}$	72	

Conclusions

The study demonstrated that adiabatic CAES is a promising energy storage technology for intermediate term application to electric utility systems due to its operational flexibility and acceptable cost. Its major competition in no-fuel systems is UPH in the 1000 MW range. The study results show that adiabatic CAES deserves serious consideration.

The author acknowledges Battelle PNL for permission to publish the study results.

PRE

ZINC-CHLORIDE ENERGY-STORAGE SYSTEMS

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Energy Development Associates (EDA) was established in 1973 by Gulf+Western Industries, Inc. to develop the zinc-chloride energy-storage system primarily for electric-utility load leveling and electric-vehicle applications. The system can be adapted for remote and standby power, marine use, and in conjunction with wind and solar-energy systems. The safe storage of chlorine at near-ambient temperatures and pressures as chlorine hydrate, $Cl_2 \cdot xH_2O$, results in the effective implementation and utilization of the high-energy zinc-chlorine electrochemical couple.

Zinc-chloride energy-storage systems have been used to power electric vehicles. Two 1/4-ton vans (Jet Industries 600) were modified in late 1979 to accept 36-kWh energy-storage systems. Similarly, in early 1980, a VW Rabbit (South Coast Technology) was retrofitted with a 36-kWh zinc-chloride system. When fully charged, this vehicle will travel 150 miles at 55 mph. Recently, EDA installed a 66-kWh/80-kW zinc-chloride system in a General Motors 3/4-ton telephone van. This vehicle is presently under test. In parallel, EDA is building three electric vehicles which were designed specifically to accommodate 50-kWh energy-storage systems. Each vehicle incorporates a Gulf+Western 2X30 Electric Engine™. This four-passenger vehicle, shown in Figure 1, has been designed to travel 200 miles (at 55 mph) on a single charge. The battery specification calls for an energy density of 90 Wh/kg and a power density of 70 W/kg. The vehicle curb weight is anticipated to be 3100 lbs. It is expected that the vehicle will accelerate from zero to thirty miles per hour in less than eight seconds.

EDA will place a 4.2-MWh system at the Battery Energy Storage Test (BEST) Facility during 1981. This system will consist of eighty 52.3-kWh Electric Load Levelers™, one of which is shown in Figure 2. The balance of plant includes a Freon-based refrigeration subsystem to allow hydrate formation during charge and a control subsystem. The facility converter will be used to interface the battery system with the electric utility grid. Following successful testing of the 4.2-MWh system at the BEST Facility, EDA anticipates construction of a 100-MWh demonstration plant in the 1984-5 time frame.

Prototype production of energy-storage units for the electric-vehicle and load-leveling applications is being accomplished at EDAs pilot manufacturing facility in Greensboro, North Carolina. This facility opened in mid-1979. Production of battery stacks began in early 1980. Assembly, testing, and qualification of full-size units will commence in late 1980. A production rate of one unit per day is targeted for early 1981. Full-scale production, i.e., 100-600 units per day, is presently being analyzed at EDA with a view to having a production facility operational by 1985.

Acknowledgments:

The author wishes to acknowledge the support of the U.S. Department of Energy (Energy Storage and Electric Energy Systems Divisions) and the Electric Power Research Institute.



Figure 1. Artist's rendition of the G+W vehicle powered by a 2X30 Electric Engine™ unit.

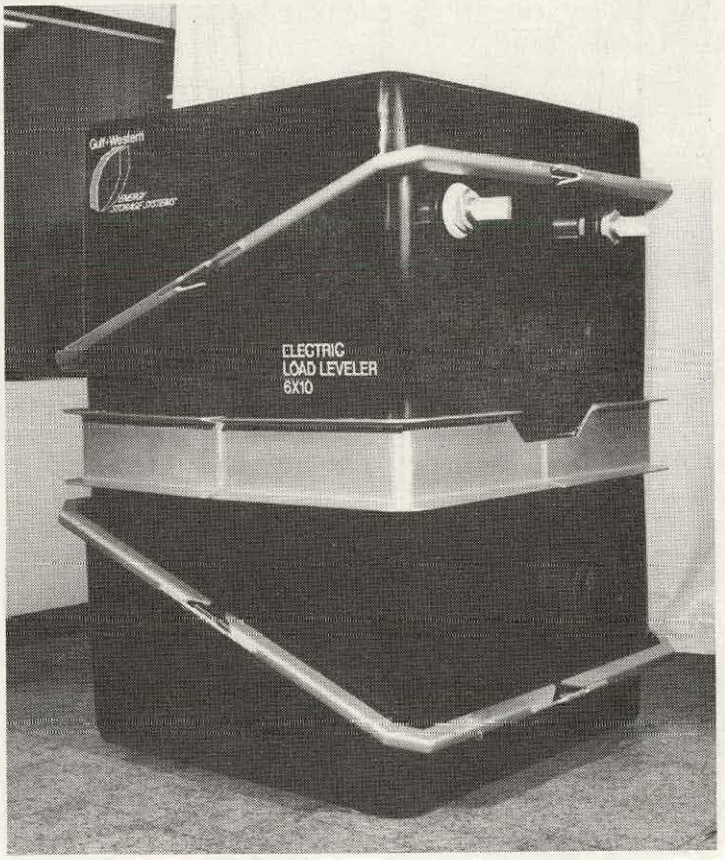


Figure 2. Prototype Electric Load Leveler™. This energy storage unit will deliver 52.3 kWh at an energy efficiency of 65%.

CUSTOMER OWNED STORAGE--THE POTENTIAL FOR BATTERY STORAGE IN INDUSTRY

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Battery storage has the potential to reduce the consumption of scarce fuels in electric energy production while at the same time reducing electricity users' costs through more economical use of existing equipment and reduced need for new equipment. To evaluate this potential Battelle-Columbus is conducting a study* to determine the feasibility of customer owned battery storage. Customers with whom DOE may subsequently participate in demonstrating the value of customer owned storage are also being identified.

This abstract discusses the scope of study. The research will be completed in the last quarter of 1980 and presented at this conference.

The initial phase of study evaluates the market potential for battery storage by customer class (e.g. SIC) and identifies individual customer attributes that impact battery storage viability. The difference between these activities is one of orientation. That is, market potential refers to characteristics ascribed to a customer class, while attributes refer to characteristics of individual firms or electricity consumers.

Important market potential characteristics being evaluated include: post demonstration diffusion potential, customer innovation potential, insurability, ability to isolate and monitor battery systems, importance of standby power, direct current energy use, and availability of time differentiated and interruptible rates. A customer attribute is considered if it impacts the relative viability of battery storage between customers. Thus electricity customers with similar attributes have similar viability although they may be in different customer classes. Significant attributes include the electricity consumption pattern of the individual customer, the schedule of electricity rates faced by the customer, availability of excess rectifier equipment and cost of capital.

Phase II of the research identifies electricity customers:

- o For whom battery storage is justified
- o Who represent a significant potential for widespread implementation and petroleum conservation
- o Who may subsequently participate in a battery storage demonstration.

Battery storage justification is based on economic viability adjusted for pertinent institutional and environmental factors. Diffusion and conservation potential analyses result in a cross matching of the attributes yielding storage viability with customer classes and their associated geographic location. Identification of potential demonstration customers is proceeding through initial inquiries to electricity customers who may have economically viable battery storage

* This research is supported by the United States Department of Energy, under contract #W-7405-ENG-92-M.

applications. Customers who express an interest in battery storage (presently ove 150) will be contacted with more specific information that will permit analysis of viability for their potential applications.

BATTERY REQUIREMENTS FOR SOLAR PHOTOVOLTAIC SYSTEMS

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Sandia National Laboratories has the lead laboratory management responsibility for the DOE funded "Batteries for Specific Solar Applications Program." The goal of this program is to develop storage battery technology in support of the various DOE solar missions. Initial program emphasis is in support of the National Photovoltaic Program. A five task program plan shown in Table I has been established to achieve this goal.

Table I - Program Plan

Task I	Battery Requirements Analysis
Task II	Laboratory Evaluation
Task III	Photovoltaic Advanced Systems Testing
Task IV	Applications Experiments
Task V	Battery Research and Development

This paper will concentrate on Task I, the Battery Requirements Analysis. Computer simulation of photovoltaic systems has been used to determine the economic feasibility of system battery storage and battery requirements have been defined. The battery requirements have been determined for energy storage in grid-connected residential photovoltaic systems. Residential systems were selected for the initial analysis because of the large potential market, the availability of information, and the existence of tax incentives. Requirements for other applications will be determined in the near future. Task II involves testing of small scale batteries in simulated photovoltaic applications. In Task III full scale batteries are being tested in Sandia's Photovoltaic Advanced Systems Testing Facility. Real world application experiments will be used to further evaluate battery systems in Task IV. Finally, the required battery technology will be developed (Task V).

In conducting the battery requirements analysis, the primary tool used was the Sandia developed SOLSTOR model, which includes off-peak battery charging by the utility, sell-back of energy to the utility and time-of-day pricing. Component cost values and other economic factors were input to the model and load, price of electricity and insolation were simulated on an hourly basis for three locations (New York, NY, Phoenix, AZ and Columbia, MO). SOLSTOR then sized the components (array, storage and power conditioning) to minimize the 20 year life-cycle cost of electricity to the homeowner.

Sellback values used in this study ranged from 0 to 75% of the utilities actual selling price. Time-of-day on-peak to off-peak price

ratios of 1, 3 and 6 were used. Another important parameter studied was the installed battery cost which ranged from $64/kWh to $270/kWh. Basic economic assumptions used included 30% income tax, 8.5% interest rate, 10% discount, 20% federal solar tax credit, 5% inflation, 0 to 6% escalation of electric rates and 1.5% annual operation and maintenance cost. It was assumed that the DOE 1986 photovoltaic price goals would be met. Efficiencies assumed were: PV array - 11%, power conditioning - 95%, battery - 80%.

The results of the analysis show that for many of the conditions considered, the cost of electricity to the homeowner is minimized by using a photovoltaic system containing battery storage. The storage capacity is generally in the 25-40 kWh range. While insolation and various economic factors play a role in the analysis, it is primarily the utility pricing structure which determines the desirability of batteries in a residential grid-connected photovoltaic system. The conclusion of the economic study is that batteries become economical at a cost of 100 to $150/kWh if: 1) the utility offers a sellback ratio of 50% or less for excess energy; or 2) a time-of-day ratio of 3 to 1 or higher is employed; or 3) time-of-day demand charges are instituted.

The specific battery requirements were extracted from an analysis of battery state-of-charge as a function of time for the various parameters. Under certain sets of conditions the battery remained in a deeply discharged state for long periods of time and generally underwent one discharge/charge cycle per day. However, in other circumstances, the average state-of-charge remained very high and the battery underwent two daily discharge/charge cycles.

The key battery requirements for residential grid-connected photovoltaic systems, derived from this analysis are shown in Table II. These requirements vary significantly from those for utility load leveling and electric vehicle applications. The need for indefinite stand times at various partial states-of-charge is unique. The random nature of the cycles and the rapid charge/discharge reversals are also specific to solar applications.

Table II - Battery Requirements For
Grid-Connected Residential Photovoltaic Systems

25 kWh capacity
Random cycles
Rapid charge/discharge reversals
Long, unpredictable stand at various states-of-charge
Maintenance free operation
$100/kWh cost for 20 year life
Non-critical energy density

Research and development efforts are being conducted with lead-acid, zinc-bromine and iron-chromium redox battery systems. Advancements in other battery systems are also being continually evaluated.

CS

BATTERIES FOR SOLAR SYSTEMS IN DEVELOPING COUNTRIES AND RURAL AREAS

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Energy storage for solar and wind energy devices presents special problems for applications in developing countries and rural areas if backup service from utility systems is impractical. The station must have sufficient battery storage capacity to stand alone or use backup systems having engine generators burning liquid fuels.

The amount of storage capacity provided depends upon the application and can be defined in terms of the number of hours or days of service the battery will provide, when it is fully charged, at the average load for the service. If year-round operation of the unit is required without a backup system, the storage battery may be designed for as much as one month of operation at the average load without recharging. As the cost of solar arrays becomes less expensive relative to that of the battery, as is expected with improvements in photovoltaic technology, the designers may choose to use larger solar arrays relative to the load. This would permit faster recharging of the battery, which may then be reduced in capacity to as little as three to five days of service for stand-alone systems. Wind energy units, even if designed for stand-alone service, usually are provided with only a few days of storage capacity.

Battery Selection for the Near Term

For the near term, lead-acid batteries should be selected for almost all situations, except for a few applications in which nickel-cadmium batteries could be considered. These applications would require long cycle life, high rates of discharge, and relatively small capacity (5 kW-hr or less) to afford the high cost ($300 to $900/kW-hr) of nickel-cadmium batteries.

Several types of lead-acid cells have been developed to meet various applications. The most common lead-acid battery, the Automotive SLI battery, has high power, but short cycle life. Such batteries can be considered for photovoltaic or wind energy applications if low first cost is a very important consideration and if deep discharges would occur relatively infrequently. Traction batteries used for forklifts and golf carts have lower discharge rate capability but longer cycle life (200-400 cycles) and may be the most cost effective battery at the present time for many solar and wind energy storage applications. Where more expense is warranted, special photovoltaic batteries are offered by some companies. These are based on the stationary type of battery that provides very long life.

The cycle life requirement is inversely related to the capacity requirement. If capacity sufficient for 15 or 20 days of storage is provided, the battery may discharge below 25% state of charge only a few times each year. Very shallow cycles of only 5% usually have little effect on the life of the battery. If only one day of capacity is provided, however, the battery may have to cycle 200 or 300 times a year and would thus require a cycle life of 2,000 cycles or more for 10-year life. For most photovoltaic and wind energy installations in rural areas, however, only 50 to 500 cycles would be required for 10-year battery life. Cycle life in this range can be achieved with batteries having lead-calcium alloy grids and designed for the photovoltaic application. Such batteries also have the important advantages of low gassing rates, low water addition requirements, low self-discharge rates, and

high efficiency. Thus, lead-calcium batteries should be chosen for most stand-alone photovoltaic and wind energy applications. However, if more than 500 cycles are required, lead-antimony type batteries may be preferred.

The price of lead-acid batteries varies considerably with the level of production and the service requirements. Golf cart batteries cost about $60/kW-hr. Batteries designed specifically for the photovoltaic application and having lead-calcium grids have low demand and low production rates and thus cost about $490/kW-hr for small cells of 175 A-hr capacity having deep discharge capability, and $235/kW-hr for 200 A-hr cells designed for shallow discharge applications. (1980 prices from C&D Battery Division of Eltra Corporation.)

Research and Development Programs

The U.S. Department of Energy (DOE) is sponsoring battery development, both for electric vehicles and for stationary energy storage applications. The Electric Power Research Institute (EPRI) is also sponsoring programs to develop load leveling batteries. Recently a program was initiated by DOE to develop batteries specifically for photovoltaic and wind energy applications; this effort is being managed for DOE by Sandia Laboratories, Albuquerque, NM.

Advanced lead-acid batteries are under development for utility load leveling applications with the goals of developing large cells (3000 to 10,000 A-hr) having very long life (>2000 cycles) and low cost. The very long cycle life may not be needed for most photovoltaic and wind energy applications and the cells developed for the load leveling application will be larger than needed for most solar storage needs.

There are three major flow systems under development: a zinc-chloride system under development at Energy Development Associates; a zinc-bromide system under development at EXXON Enterprises, Inc., Gould Inc., and General Electric Company; and reduction-oxidation systems under development at NASA-Lewis Research Center. These systems have in common the use of tanks outside of the electrode compartments to store active materials. The zinc anode systems store only the halogens in tanks, and the reduction-oxidation systems store both anolyte and catholyte solutions. The reduction-oxidation systems have the potential advantages of high efficiency (>75%) and low cost for additional capacity which is obtained by increasing the amounts of the solution and the capacity of the storage tanks.

Two types of high-temperature systems are now under development: sodium/sulfur batteries and lithium/metal sulfide batteries. These systems operate at 350°C and 450°C, respectively. Both types of high-temperature batteries require an insulating jacket to maintain the operating temperature. The heat to maintain the temperature is derived from the normal irreversible losses on operation of the batteries which amounts to about 30% of the energy charged for these batteries. It is impractical to operate a small battery of these types at the temperatures required; a capacity of at least 100 kW-hr is the minimum practical size for stationary energy storage batteries, although smaller sizes may be practical for electric vehicle applications by use of a vacuum insulating jacket.

When fully developed, one or more of the advanced systems may be less expensive than lead-acid batteries. For stand-alone service, which may be needed in developing countries or some rural applications, the large storage requirement relative to the load appears to favor the reduction-oxidation flow systems which may have a low marginal cost for additional capacity. However, for many applications it may not be economical to store energy sufficient for several days when compared to only one da of storage and a backup energy system such as an engine-generator.

CS

SOLAR RELATED FLYWHEEL SYSTEMS*

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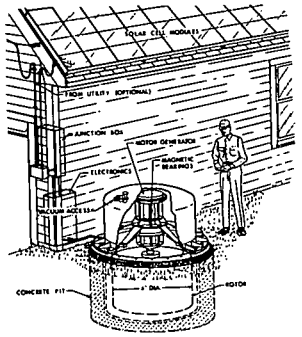


Fig. 1. Residential PV flywheel storage system.

C71-1055

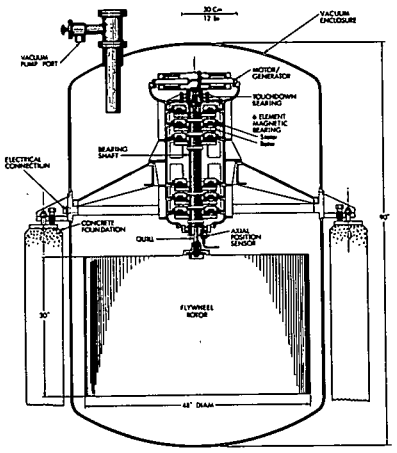


Fig. 2. 40 kWh residential flywheel.

C74-1060

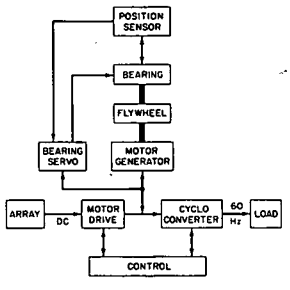


Fig. 3. Flywheel system schematic.

Flywheel energy storage systems for use with residential photovoltaic (PV) installations are being developed by MIT Lincoln Laboratory (MIT LL). In this approach, electrical energy from solar cell modules is stored in the flywheel during sunny periods and removed from the flywheel as required to meet the electrical demands of the residence, Fig. 1. An innovative flywheel system design is being pursued which utilizes a magnetic rotor suspension system, a high energy rotor, and integrated rotor drive and power conditioning electronics to produce a technically and economically competitive storage system. During the past year, a 40-kWh residential flywheel system with these features has been designed, Fig. 2, with an overall system schematic as shown in Fig. 3. The noncontacting magnetic bearings have significantly lower drag and longer life than alternative ball bearing and fluid bearing types and the flywheel is run in a vacuum to eliminate rotor aerodynamic drag. Thus longer storage times are possible, since the fraction of stored energy devoted to fixed losses is sharply reduced. Electricity from the PV array may be used simultaneously to power up the flywheel or to power the cycloconverter which supplies 120 volt, 60 Hz AC to the load. Integration of the DC drive motor, the permanent magnet alternator, and the cycloconverter within the unit produces a flywheel system which functions as a storage device and as a DC to AC converter, accomplishing the latter function at a lower cost than the separate inverters normally required in any PV application.

Manufacturing cost studies of the first-generation, 1980 technology, 40-kWh residential flywheel design layout, Fig. 2, were prepared by three industrial contractors for production rates of 1000, 10,000, 100,000 units per year. Cost projections for the 10,000 per year rate, summarized in Table I, predict an installed price ranging from $17,000 to $21,000. In the course of the work, each of the

*This work was sponsored by the U.S. Department of Energy. The U.S. Government assumes no responsibility for the work presented. DOE/ET/20279-106

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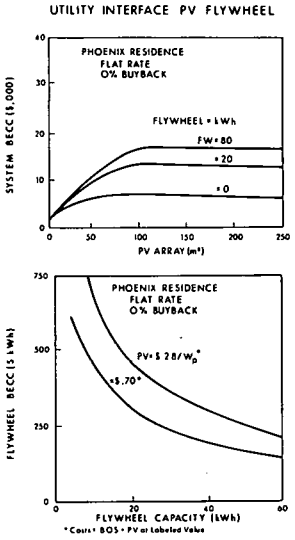


Fig. 4. BECC for utility interactive Phoenix PV residence.

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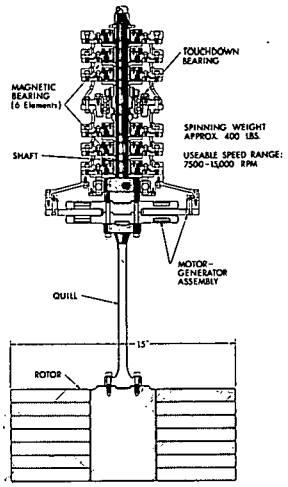


Fig. 5. 1/10 scale experimental flywheel.

contractors suggested a number of design changes that might be instituted to improve manufacturability and lower cost. It was estimated that these improvements could reduce the cost of the next generation flywheel design by 30% or more. More recently, simplifications in magnetic bearing and motor-generator design also suggest that additional system cost reductions are possible, with final system costs projected in the $8,500 to $11,000 range.

Flywheel energy storage economics have been studied in an MIT Energy Laboratory system-worth analysis[1] which considered utility-interactive and stand-alone family residences with an 8-kW-peak PV array in Boston and Phoenix locales. An example of system (PV plus flywheel) break-even capital costs (BECC) and flywheel BECC for a utility-interactive residence in Phoenix, Fig. 4, shows that the addition of storage serves to increase the optimum capacity of installed PV when hardware costs are assumed low enough to yield a positive return on investment. It also predicts a 40 kWh flywheel BECC in the range of $200-$300/kWh, a BECC comparable to manufacturing costs.

A laboratory, 1/10-scale, 1-4 kWh version, Fig. 5, of the residential flywheel unit has been constructed and tested by MIT LL and performance and efficiency measurements have been made at rotational speeds to 15,000 rpm with a 400-lb. steel disc rotor. These tests showed that this system is the equal of or superior to battery/inverter systems for the same application, Table II. In one set of tests, the flywheel was operated continuously and functioned perfectly for over 2200 hours at a nominal speed of 10,000 rpm. A maximum power loss of only 3 watts was measured at 15,000 rpm (0.6% of the stored energy per hour) for the combined effects of armature eddy currents and bearing magnetic hysteresis. The output waveform from the cycloconverter is excellent, with current harmonic distortion of 0.5%.

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1. Dinwoodie, T.L., "Flywheel Storage for Photovoltaics: An Economic Evaluation of Two Applications," MIT Energy Laboratory Report MIT-EL-80-002, February 1980.

Table I

MANUFACTURING COST ESTIMATES
40 kWh, 8 kW
FLYWHEEL ENERGY STORAGE UNIT
• 10,000 UNITS PER YEAR 1980 TECHNOLOGY AND DOLLAR COSTS

ORGANIZATION	THEODORE BARRY	GARRETT AIRESEARCH	KELSEY-HAYES RESEARCH	MIT LINCOLN LABORATORY(3)
FLYWHEEL ROTOR	4,000(2)	4,000(2)	4,000(2)	5,000
MOTOR-GENERATOR	2,200	2,100	2,300	1,700
MAGNETIC BEARING ASSEMBLY	2,600	4,100	5,100	2,500
VACUUM SYSTEM AND ENCLOSURE	2,400	1,100	1,500	1,200
ELECTRONICS	1,200	3,500	2,600	1,800
SYSTEM CHECKOUT	200	500	1,200	-
INSTALLATION	1,000	1,500	900	800
SUB TOTAL	13,600	16,800	17,600	12,500
MANUFACTURING MARKUP AND DISTRIBUTION	3,400	5,000	2,700	-
TOTAL	17,000	21,800	20,300	-

(1) PRELIMINARY
(2) FLYWHEEL COST SPECIFIED BY MIT LINCOLN LABORATORY
(3) A.B. MILLNER, A FLYWHEEL ENERGY STORAGE AND CONVERSION SYSTEM MIT LL REPORT COO-4094-48

Table II

MEASURED EFFICIENCY FLYWHEEL ENERGY STORAGE AND CONVERSION SYSTEM
vs
BATTERY INVERTER AND MAXIMUM POWER TRACKER SYSTEM

FLYWHEEL BASED SYSTEM		
DC MOTOR ELECTRONICS	94 PERCENT	
DC MOTOR	96	
AC GENERATOR	90	
BEARINGS AND TARE	95	(1-1/2% Stored Energy Per Hour)
GENERATOR ELECTRONICS	88	
TOTAL	68 PERCENT	
BATTERY BASED SYSTEM		
MAXIMUM POWER TRACKER	96 PERCENT	
BATTERY	80	
INVERTER	85	
TOTAL	65 PERCENT	

Dup

A SURVEY OF BUILDING HEATING/COOLING STORAGE*

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Introduction

Renewable energy sources have the potential for supplying significant portions of residential and commercial building heating and cooling requirements. Thermal conversion systems — active and passive solar, and biomass — are under intense development; storage is a critical factor for the successful implementation of such systems. Storage already is playing an increasingly important role in energy conservation and utility load-leveling assignments. The Office of Advanced Conservation Technologies of DOE sponsors the development of thermal storage technology. On-going programs are in the areas of storage for Solar Applications, Utility Load Management and Energy Conservation.

The technologies of storage required for use with renewable energy sources are partly those being developed for conservation and load management and, in addition, those unique to the needs of utilizing solar energy. Advanced techniques will contribute to conservation of finite, depletable energy sources only where they are widely applied and accepted. This requires a technology producing storage systems which perform, are cost-effective, reliable, safe, and provide thermal comfort.

Thermal storage is but a part of a total energy capture and use system. Its nature and function realistically must be dictated by the energy source and energy use conditions. Therefore, a review of storage requirements for various systems is in order.

Renewable Energy Storage Requirements

Cool-side storage from solar absorption chillers requires storage at 40-50°F for intervals of one to three days. The use for the stored cool is space cooling.

Collection of heat for diurnal heating/cooling load leveling requires storage at 70-80°F for 8- to 12-hr times.

Active, flat-plate solar collection for space heating utilizes storage temperatures of 80-120°F over one- to three-day periods.

Active, focussed solar collectors require 180-250°F, one- to three-day hot-side storage for solar absorption chillers.

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*Research sponsored by the Division of Energy Storage Systems, U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation-Nuclear Division.

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Storage Materials

The list of materials practically suitable for storage is not long:

- Storage of sensible heat in water, rocks, and ceramics
- Storage of latent heat of fusion in ice, hydrated salts, wax, and other phase-change materials

The probability of the list being expanded except in new formulations of eutectics of salt hydrides is small. All of the candidate materials have, despite some disadvantages, a good chance of being incorporated into a useful storage system.

- Cool-Side Storage, 40-50°F
- Diurnal Load Leveling, 70-80°F
- Active Solar Heating, 80-120°F
- Absorption Chiller — Hotside Storage, 180-250°F
- Diurnal Storage of Biomass Conversion, 200-1200°F
- Annual Cycle Storage of Cold, 32-40°F

Present System Technology

Technology for utilizing the available storage materials in projected thermal storage systems is represented in commercial storage of chilled/heated water, commercially available utility load leveling and energy conservation heat storage systems, the many demonstration programs involving prototype hot and cool storage devices, and development programs currently in progress. Remaining needs for R&D are in packaging, heat transfer mechanisms, and reliability. Some critical considerations are:

- Thermal stratification of water tanks
- Improvements in low-cost containers
- Development of reliable phase-change materials with little or no subcooling, small temperature range of transition, high degree of reversability, and long-time stability
- Reliable, efficient heat transfer configurations between the storage material and the collection heat transfer fluid

Outlook

The fully developed thermal storage systems which become widely used will most probably utilize the present list of available storage materials. The role of and need for thermal storage is recognized. The problem before us is the optimization of systems utilizing the candidate materials. For residential applications, storage of energy in forms other than thermal do not, because of the technology involved, appear to have potential for becoming economically competitive with thermal storage.

The economics of thermal storage do not help the economics of solar energy systems. Solar components are inherently expensive, and the achievement of low-cost systems must be through development of those components. Although thermal energy storage does not save energy, i.e., increase the efficiency of solar collection and use, the storage losses can be made acceptably low for a diurnal system.

The requirements for thermal storage are not new storage materials but improved, clever, cost-effective — packaging, heat exchange configurations, reliability, and performance.

CS

THERMAL ENERGY STORAGE SYSTEMS FOR THE PULP AND PAPER INDUSTRY

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The pulp and paper industry is a major industrial user of energy in the United States. Recent studies have indicated that substantial reductions in a mill's net energy requirements can be realized by application of thermal energy storage (TES) system technology. TES is a technique whereby mill generated energy is stored to subsequently meet the rapidly varying or "swinging" process steam demands of mill operation. The storage system can accept either externally generated energy (e.g., energy generated from a hog fuel boiler) or internally generated energy (e.g., reusable energy released from a production operation).

The TES concept is not as widely applied today in the U.S. pulp industry as it is in some international mills, especially within Scandinavia. The reason for this is the higher fuel prices that have persisted for several previous decades in Scandinavia compared with energy costs in the United States. Thus, sufficient economic incentive has not previously existed in the United States to provide the thrust for application of TES system technology. Now however, U.S. conditions of high energy costs warrant its application.

This paper describes a Department of Energy (DOE) study (administered by NASA) presently underway which has as its purpose the collection and dissemination of TES system technology for the pulp and paper industry with the intent of reducing fossil fuel usage. Table 1 presents some of the mill applications selected for detailed investigation. The results of the overall study will be completed early in 1981.

Table 1: TES System Application Identified for Further Study

No.	Production Type	ton/year (metric)	Application
1	Dissolving Newsprint	140,000 245,000	Steam accumulator TES system to store steam during paper machine breaks.
2	Sulfate (sack) Sulfite (Unbleached)	170,000 160,000	Mill owned boiler to provide district heating for adjacent community TES system is hot water accumulator for mill transient hot water energy demands. Start-up scheduled September, 1980, permitting before/after evaluation of energy demands.
3	Newsprint	170,000	Steam accumulator TES system to store steam during paper machine breaks and utilize steam when paper sheet is brought to full width.
4	Sulfate	240,000 (Bleached) 70,000 (UNbleached)	Ruth accumulator between boilers and batch digesters.

Table 1: (Continued)

No.	Production Type ton/year (metric)		Application
5	Sulfate	218,000 (Pulp) 286,000 (Paper)	Steam accumulator for balancing steam production from recovery boiler in relation to batch digesters and board machine.
6	Sulfate	135,000 (Bleached) 35,000 (Unbleached)	Steam accumulator for reducing mill-wide variations in energy demand.

A ranking criteria is being developed to identify mills having a high potential for TES system application. The following items should be considered when developing a ranking criteria:

- Plant layout and site-specific problems in transfering TES from one collection point to an important use point.
- Mill steam demand fluctuations including repetitiveness of rapidly varying or "swinging" process steam demands.
- Mill complexity, with an integrated mill having more potential use areas, assuming other factors remain constant.
- Local comparative cost both at current and projected future conditions for hog fuel, purchased electricity and oil.
- Bark boiler capacity limitations and its potential for excessive air pollution emissions at higher boiler loading conditions.
- Availability of existing equipment to serve as the energy storage vessel (such as an "old" batch digester), thereby affecting the cost effectiveness of the TES system.
- Age or degree of mill modernization which can affect the corporate decision on capital investment for a TES system.
- Possibilities of local accelerated ammortization or tax considerations which affect the decision-making process.
- Mill expansion plans which can either facilitate a timely TES installation or delay a TES decision until the expansion is completed and a new heat-power balance is determined under actual operating conditions.

Results of the actual mill field studies will be presented. Preliminary information will also be presented on an U.S. industry-wide basis for energy conservation, economic analysis and an environmental impact assessment.

PRE

DEVELOPMENT AND DEMONSTRATION OF AQUIFER THERMAL ENERGY STORAGE

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The Office of Advanced Conservation Technologies of the United States Department of Energy is responsible for formulating and managing research and development in energy storage technology. The Pacific Northwest Laboratory (PNL) has been assigned the responsibility, through the Richland Operations Office, for management of the Seasonal Thermal Energy Storage Program (STES).

Storage of thermal energy is expected, in the near term, to provide a significant contribution toward achieving the goals of the National Energy Plan. This contribution will encourage a shift from use of insufficient or costly fuels such as oil and natural gas to more abundant or available energy sources such as coal, solar, and nuclear power. Thermal energy storage, when incorporated in energy supply and conservation systems, permits efficient and economical use of intermittent energy sources such as solar or off-peak electrical power. Thermal storage also may allow use of waste heat from industrial and utility sources.

The STES Program is designed to demonstrate the storage and retrieval of energy on a seasonal basis, using heat or cold available from waste or other sources during a surplus period to reduce peak period demand, reduce electric utility load problems and contribute to the establishment of favorable economics for district heating and cooling systems for commercialization of the technology. Aquifers, ponds, earth, and lakes have potential for seasonal storage. The initial thrust of the STES Program is toward utilization of ground-water systems (aquifers) for thermal energy storage.

During the last decade, the storage of thermal energy in aquifers has received considerable attention. The motivations for storing large quantities of thermal energy on a long-term basis have been numerous including: a) the need to store solar heat that is collected in the summer for use in the winter months; b) the costs effectiveness of utilizing heat now wasted in electrical generation plants; c) the need to profitably use industrial waste heat; and d) the need to more economically provide summer cooling for buildings. Seasonal aquifer storage should contribute significantly to satisfy the above needs. Most geologists and ground-water hydrologists agree that heated and chilled water can be injected, stored, and recovered from aquifers. Geologic materials are good thermal insulators, and there are potentially suitable aquifers distributed throughout the United States. Recent studies and small-scale field experiments have reported energy recovery rates above 70 percent for seasonal storage. By the year 2000, seasonal aquifer storage could replace or conserve up to 350 million barrels of oil per year. However, successful demonstration of large-scale aquifer thermal energy storage has not yet been attempted and the concept's economic feasibility and institutional acceptability have yet to be established.

In field tests of thermal energy storage in aquifers performed by Auburn University, 54,784m^3 of water were pumped from an aquifer, heated to 55°C, and injected into a deeper confined aquifer where the ambient temperature was 20°C. After a storage period of 51 days, 55,345m^3 of water were produced from the confined aquifer. During the 45 day production period the temperature of the produced water varied from 55°C to 33°C, and 66% of the injected thermal energy was recovered.

In 1978, in a second cycle 58,010m^3 of 55°C water were injected, stored 63 days, and 66,400m^3 of water recovered. Water produced varied in temperature from 54°C to 33°C, and 70% of the injected thermal energy was recovered.

Auburn now plans three additional cycles. The well field will be modified to a true doublet in a confined aquifer. The three cycles will then be:

Injection Temperature	Length/Cycle	Energy Injected (MW Hr [Th])
55°C	Injection 2 months	2647
90°C	Storage 2 months	5294
125°C	Recovery 2 months	7941

Three demonstrations of thermal energy storage in aquifers have been initiated. Each demonstration combines an energy source, aquifer storage, and a beneficial use. Phase I contracts now in place will include aquifer characterization, development of functional criteria in mid-1982.

The three demonstrations include:

Contractor	TRW Incorporated	Dames & Moore	Univ. of Minnesota
Location	Bethel, Alaska	Stony Brook, New York	Minneapolis, Minnesota
Type	Heat 95°C	Chill	Heat 150°C
Energy of Source	Diesel Exhaust & Cooling Water	Cooling Tower	Cogeneration Steam
Energy Use	District Heating	Building Air Conditioning	Campus Heating

Phase I will be followed by Phase II cost shared contracts for construction and operation. Phase II will be completed in 1985.

In the overall STES program; institutional and environmental issues affecting commercialization of aquifer storage are being evaluated. A generic Environmental Assessment is under preparation, and site-specific environmental documentation is being prepared for each demonstration. The program is designed to provide the technical information, economic data, and operational experience essential to provide a base for municipalities, utilities, and industry to evaluate and adopt this method of achieving more effective use of available thermal energy supplies.

PRS

LEGAL, REGULATORY, AND INSTITUTIONAL CONSIDERATIONS FOR AQUIFER THERMAL ENERGY STORAGE

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Aquifer thermal energy storage is a technological possibility. It holds the promise of narrowing the seasonal gap between the availability and demand for thermal energy, especially for space heating and cooling. The U.S. Department of Energy has funded a major program to demonstrate the technological and economic feasibility of aquifer thermal energy storage. The goal of the U.S. Department of Energy is to pave the way for commercial application of seasonal energy storage and use through aquifer systems.

Widespread application of aquifer thermal energy storage will mean attracting large sums of private capital to invest in this energy system. How attractive aquifer thermal energy storage is to financial institutions and developers alike will depend upon long-term security in aquifer use. Risks or uncertainties associated with land and water rights and environmental protection requirements must be controlled by legal, regulatory, and institutional systems. Similarly, legal and regulatory systems must provide protection to other existing and future users of aquifers in order to gain public acceptance of aquifer thermal energy storage systems. Public trust in aquifer management will ultimately determine the fate of commercial application of aquifer thermal energy storage technology.

Aquifer use for energy storage is a water management matter. State water right laws along with state and federal pollution and drinking water laws should be examined for their adequacy in reducing the uncertainties associated with aquifer use. Western states water laws pose interesting questions for aquifer thermal energy storage. The application of water rights to the use of aquifer space, injection water, and water withdrawals are subjects needing legal clarification. The capability of water administrators to protect storage aquifers from invasion by indiscriminate uses of ground waters poses a potential detriment to aquifer energy storage. Many states, for example, have no control or limit their control of water wells to only the larger users.

State and federal environmental policy acts should be used to examine individual storage projects, obtain public confidence, and ease the regulatory and licensing processes. Experience in low head hydro development shows promises of environmental policy acts reducing the difficulties in obtaining permits and licenses. Generic environmental assessments will reduce

the number of project statements needed in the long-term application of aquifer thermal energy storage.

The Federal Safe Drinking Water Act gave nationwide emphasis to the protection of ground water from improper disposal of waste. The Underground Injection Control Program created by this act will be a major influence on the management of aquifer thermal energy storage systems. In many states, this will mean the establishment of legal and administrative systems for the management of aquifer use separate from those designed to allocate water to beneficial uses.

State and federal water pollution control laws regulate the discharge of waste to waters of the United States. This includes the regulation of discharges to ground water in many states. Water quality standards for ground water will become, if not already, a feature of most State Water Quality Standards regulations. However, the setting of ground water quality standards is focusing on traditional ground water uses, primarily drinking water. The use of aquifers for energy storage is a beneficial use of water which must be recognized in setting these standards. Commercial use of aquifer energy storage will require a broadening of beneficial use concepts for ground water, let alone, some serious long-term planning for aquifer management. In the development of ground water quality standards extreme caution should be utilized not only to assure that the resource is protected, but equally important, to assure that the door to environmentally sound aquifer thermal energy storage projects remains open.

Water, whether flowing on the surface of the land or in the ground, is a precious commodity. The history of water management in the western United States is full of controversy and conflict over a scarce resource. Over the past 100 years legal systems of allocating water have evolved, producing international treaties, interstate compacts, and state allocation systems that are jealously guarded by state administrators. Failure to develop aquifer use within these accepted systems of water allocation and management could become the largest impediment to commercialization of aquifer thermal energy storage systems.

MOLTEN SALT STORAGE TECHNOLOGY DEVELOPMENT*

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Recognizing thermal energy storage as potentially critical to the successful commercialization of solar thermal power systems, the Department of Energy (DOE) has established a comprehensive and aggressive thermal energy storage technology development program. The overall objective of this program is to develop general solar thermal energy storage technologies that provide: (1) second-generation storage subsystems offering cost/performance improvements over the first-generation storage subsystems currently being developed for solar thermal power applications; (2) first-generation storage subsystems for those solar thermal applications that presently have no storage subsystems under development, and; (3) a technology base to support storage subsystem development for future solar thermal power applications. Molten nitrate salts have been proposed for use as primary heat transfer and thermal energy storage media in some solar thermal power applications. Nitrate salts are of interest because they are abundant, readily available and inexpensive, and have excellent thermal properties and low vapor pressures. However, salt physical properties, corrosive behavior, and environmental effects are not well known over the temperature range of interest, 350 to 600°C. In addition, while molten nitrates have performed satisfactorily for many years as a heat transfer fluid and as a heat treatment bath medium, solar applications place more rigorous demands on the salt.

The salt composition of greatest interest is drawsalt, nominally a 50-50 molar mixture of $NaNO_3$ and KNO_3 with a melting point of 220°C. Several technical uncertainties have been identified, and must be resolved before nitrate based solar plants can be commercialized. Research programs at Sandia National Laboratories, universities, and industrial suppliers have been implemented to resolve these technical issues. Areas of investigation include salt decomposition, corrosion, and thermophysical properties studies.

Decomposition Studies--It is recognized that nitrate salts, when heated, can degrade by numerous different reactions. The extent to which these degradation reactions impact the use of salts in energy systems has not been determined with certainty. In addition to thermal decomposition, the salts may react with CO_2 and H_2O vapor in the air seriously affecting salt physical properties such as melting point, thermal conductivity, etc. Studies are currently being conducted to understand the thermal decomposition and reaction mechanisms and kinetics for salt interactions with CO_2 and H_2O. Results from these experiments will be used to assess the need for a salt regeneration or purification subsystem in a solar thermal power system.

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Corrosion Studies--Molten nitrates do not appear to create an overly severe corrosive environment. Static immersion tests have shown that general corrosion takes place by oxidation. Several thermal convection loops have been built using alloys being considered for use in central receivers: Incoloy 800 and 316 and 304 stainless steels. Metal coupons are suspended in the loops which are used to evaluate the corrosion behavior of the alloys in molten nitrate salts and to ascertain if thermal gradient mass transfer phenomena significantly affect corrosion behavior. Below 600°C corrosion is relatively benign although samples lose weight due to chromium depletion. At temperatures above 600°C, corrosion and depletion rates are several times faster. Further experiments are required to clarify the temperature limit for acceptable corrosion rates. In addition, some loops are being operated open to the air while others are being run with an inert cover gas. Results from these experiments should identify potentially different corrosion rates due to salt impurities such as carbonates and hydroxides derived from atmospheric interactions. Experiments to assess the potential for environmental corrosion cracking (i.e., the coupled interaction of the molten nitrate environment and applied stress on containment alloys) are also underway. Preliminary results indicate no adverse corrosion cracking due to molten salt.

Thermophysical Properties Studies--Data such as viscosity, surface tension, density, heat capacity, and thermal conductivity are needed from 350 to 600°C. These data are required by the designers and engineers of solar thermal power systems in order to size hardware and for thermal modeling of the system. Experiments to determine these properties of drawsalt are in progress. Thermophysical properties of drawsalt plus impurities such as nitrite, carbonate, and hydroxide are also being measured. These studies will impact the need for a salt purification subsystem.

The information derived from the above studies will impact decision points set by DOE for the development of thermal storage technologies matched to solar thermal power system requirements for several near-term Central Receiver applications such as the repowering/industrial retrofit program. This program has two applications: repowering of existing electric power generating plant and retrofitting of existing industrial process heat plants. The molten nitrate salt experimental program has been designed to meet the needs of the repowering/industrial retrofit program in a timely fashion.

PRC

OVERVIEW AND TEST RESULTS OF THE DEPARTMENT OF ENERGY'S ELECTRIC VEHICLE BATTERY PROGRAM

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Over fifty percent of the oil imported today by the United States is consumed by the transportation sector in moving people and goods. This dependence on foreign oil can be reduced by powering electric vehicles (EV) with energy generated from coal, nuclear, and solar. To promote this fuel shift, the Department of Energy (DOE) is aggressively pursuing the development and demonstration of improved electric vehicles. A major program thrust in improving the performance of EV's is the development of better batteries. This requires the simultaneous improvement in the battery's specific energy (range), specific power (acceleration), life and cost. Improvement in two, or even three, of the four variables has traditionally been possible, but the simultaneous improvement of all four is presenting a substantial challenge to the battery developers. The DOE through cost-shared programs with industry is funding the early high risk research, development and demonstration of these batteries. The ultimate success of the program will be measured by the number and types of batteries commercialized by industry.

The DOE electric vehicle battery program is divided into: (1) Near-Term Batteries, (2) Advanced Battery Development, and (3) Electrochemical Systems Research. The near-term program was established to support the Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976 (P.L. 94-413). To support the Act, improved battery technology must be available before or by 1984. The advanced battery technology, with more energetic systems and higher performance goals, is expected to be available for EV's built in the late 1980's and beyond. Electrochemical System Research emphasizes advanced couples whose development has not yet progressed to the full-size cell/battery stage. The total current funding (FY 1980) for EV battery development is $20M while the projected FY 1981 funding is $24.1M. This funding is divided as follows: (1) Near-Term-$10.5M (FY 80)-$12.9M (FY 81), (2) Advanced-$7.8M for both FY 1980 and 81, and (3) Electrochemical Systems Research $1.7M (FY 80)-$2.5M (FY 81).

Near-Term - The near-term battery program was initiated in 1978 with program emphasis on technological improvement resulting in the demonstration of full-size vehicle batteries (20-30 kWh) that can be commercialized by 1986. Initially, three battery types (lead-acid, nickel/iron, nickel/zinc) were being developed by eight contractors. In November 1979 a fourth candidate, zinc/chlorine, based on its rapid progress in the advanced program was transferred to the near-term. These four battery types were selected for their potential to accomplish the required improvement in the time period specified and their ability to be commercialized by 1986. As of July 1980 good progress has been shown by the test results measured on full-size lead-acid (Pb-A), nickel/iron (Ni/Fe), and nickel zinc (Ni/Zn) cells which have been evaluated at the National Battery Test Laboratory (NBTL) or at the battery developers. However, cycle life for Ni/Zn still remains a problem. Table 1 compares the 1980 performance goals versus status of improved Pb-A, Ni/Fe, and Ni/Zn full-size cells. In addition to updating these results, in-vehicle tests of full-size

engineering batteries including a 36 kWh zinc/chlorine battery are scheduled for evaluation in the Fall of 1980 and will be presented.

TABLE 1 - Comparison of 1980 Performance Goals Versus Test Results As of July 1980

	Commercial Pb-A	Improved Pb-A		Ni/Fe		Ni/Zn	
		Goal 1980	Status 7/80	Goal 1980	Status 7/80	Goal 1980	Status 7/80
Specific Energy (Wh/kg)	30	42	41	54	48	64	69
Specific Peak Power (W/kg)	70	105	120	110	103	110	133
Cycle Life	250	400	640	300	327	200	127

Advanced Batteries - The advanced battery program is expected to provide batteries with more power (acceleration) and energy storage (range) capability in smaller volumes and at lighter weights than their near-term counterparts. They should enable electric vehicles to obtain a range of 150 miles or more and to accelerate at speeds equal to heat engine vehicles. The advanced battery goals include a specific energy 140 Wh/kg and a specific power of 200 W/kg. Currently, two high temperature battery types are being developed, namely a lithium/metal sulfide system (425°C) and a sodium/sulfur system (300°C). During FY 80, the lithium/metal sulfide program has concentrated on building and testing full-size 300 Wh cells. Initial results indicate that specific energies of 90 to 100 Wh/kg are being obtained. Also, the development and use of a less expensive boron nitride seperator has been demonstrated in biplate cells which have completed 277 cycles. The program emphasis in sodium/sulfur (ceramic electrolyte) development is primarily on load leveling batteries; however, system analysis and design trade-off studies are being conducted for certain EV missions. These suggest that a battery/battery hybrid (Na/S energy battery coupled with a small lead-acid power battery) is the preferred approach and that a cell size of 60-100 watt-hours is desirable. The current load leveling cells (240 Wh size) exhibit 120 Wh/kg. This technology would translate to about 100 Wh/kg in the smaller EV cells.

Electrochemical Systems Research - Under this program element both aluminum/air and iron/air systems are being developed for EV application. The aluminum/air system is being developed as a mechanically rechargeable battery which will be competitive in range with today's heat engine vehicle (250 miles or more). During 1980, scale-up from laboratory size cell (50 cm^2) to full-size (100 cm^2) has been accomplished with no degradation in performance. Program emphasis during FY 1981 will concentrate on building and testing full-size multicell stacks and on the design for mechanically replacing the aluminum plates. The iron/air system is an ambient temperature electrically rechargeable system which offers promise of a low cost battery system for a 150-mile range EV. Program emphasis at the current time is to increase the cycle life of the rechargeable air electrode from 200 to 800 cycles in a design which is economical to manufacture.

POTHOLES AND PITFALLS: THE ROAD TO AUTOMOTIVE DESIGN

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The time is long gone if, indeed, it ever existed, that the design of the automobile could be regarded as merely technical or, in fact, that the automobile itself could be considered simply a technological phenomenon. It is, essentially and almost uniquely, a sociological phenomenon, a creation of its political, economic, cultural, and industrial milieu. As such, it is both cause and consequence of interlocking social forces and factors. It is our contention in this paper that the automobile's interrelationship with the larger society complicates the design process to the point of denying the "rationality" of present day decision-making tools and defying the cherished canons of management science so prevalent in the U.S. business community.

One might go so far as to say that the techno-economic model that dominates much of American "planning" in government and private industry alike is the root cause of many of our current problems and not, as is presumed, the remedy for them. Let us consider the principles of management-by-objective, productivity, and cost/effectiveness. Mutually self-sustaining, they have rationalized a short-term orientation but have been detrimental to the long-term planning essential to the health of the American industrial enterprise. Moreover, they sanction the knee-jerk response known as the cost/benefit calculation when what is called for is wide-lensed evaluation. It should come as no surprise that the underlying philosophy, that of "the biggest bang for the buck", emanates from former Secretary of Defense Robert S. McNamara's industry-based managerial techniques of systems analysis, risk analysis, and the like. These have become the core curriculum of the nation's business schools and have created the management syndrome. This is the dominant paradigm; it explains why corporate executives do not know when they are wrong; it explains why they respond inappropriately to warnings in the real world; it rationalizes the "technical fix"; it sanctions slogans where solutions are needed; it will provide inappropriate guidelines to the future.

Management-by-objective appears obvious to the point of banality. And yet, applied to the automotive industry, it raises important questions about priorities - who is to set them; by what standards. Recent revelations about the demise of Detroit suggest that a choice has been made between product quality and profit; the latter won. But victory was short-lived. Confidence in the American automobile was undergoing erosion at the very time that management was applying its inappropriate measures. Thus, cost/effectiveness was tantamount to caveat emptor. The manufacturer faced with a huge recall turns to the courts instead of returning to the drawing board or repairing the defective cars on the road.

The American automotive industry attributes its woes to "consumerism, pollution, and regulation". But these are the very factors that are boosting the sale of imported models. Detroit's derision of and disdain for consumerism has driven the American customer to buy cars responsive to his or her needs and not models designed with industry profit as the objective. Consumers knew, without the benefit of business-school seminars, that the slogan, "What is good for General Motors is good for the country", is a myth. They knew, moreover, that the current "re-indus-

trialization" is more slogan hokum. It is not even a band-aid to cover the wounds created by the productivity objective that reduced the production process to a cynical numbers game. Pride-of-workmanship has been rendered as anachronistic as the horse-and-buggy. The car of the future will not come from econometric models, replete with numbers about projected energy supply and demand, alternate energy sources, and the like. The car of the future will depend on the shape of life of the future and this is beyond calculation. In the final analysis, the social facts of life, even though not precisely quantifiable, are precisely those that count.

We must, therefore, consider the changing societal context of the automobile. While this may not lend itself to numerical expression, which is debatable at best, we can identify trends that are significant. Measurement, we agree with Georgescu-Roegin,[1] serves no useful purpose, since it "can be obtained only by an intentionally mutilated representation of reality". (Italics added) The reality is that we are facing an era characterized by new conceptions of global resources. We are beginning to recognize the limits of the earth's capacity to provide a cornucopia on the one hand and to absorb all the effluents of a burgeoning world population on the other. With ecological goals to be respected, we begin to perceive the dangers of social hedonism. Even if gasoline were abundant and cheap, the atmosphere could not tolerate the pollution created on the highways by conventional engines. One-man-one-gas-guzzling car on overcrowded highways would ultimately mean less mobility for everyone. Declining birth rates and an aging population negate the presupposition that lurking behind every wheel is an Evel Knievel. Senior citizens, whose first priority is neither to go far nor fast, will comprise a large proportion of the American buying public. Changing societal values are embedded in a newly-emerging social paradigm, the outlines of which can be dimly seen in the Global 2000 Study.[2] This reconnaissance of the future serves as both warning and guideline with respect to energy prospects and policy, and particularly to transportation technology, which can play a vital role in shaping a viable future.

[1] Nicholas Georgescu-Roegin, The Entropy Law and the Economic Process, Cambridge, Massachusetts, Harvard University Press, 1971, p.83.

[2] Department of State and Council on Environmental Quality, The Global 2000 Report to the President: Entering the Twenty-first Century, Washington, D.C., U.S. Government Printing Office, 1980.

FE 9

THE GA SULFUR-IODINE WATER-SPLITTING PROCESS - A STATUS REPORT

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Abstract

Continued development of the General Atomic sulfur-iodine thermochemical water-splitting cycle has brought the system to a considerable state of maturity:

1. The operation of the cycle has been demonstrated under recycle conditions in a closed loop demonstrator;
2. An engineering flowsheet has been designed, resulting in a calculated thermal efficiency of 47%;
3. The installation of the first level scaleup system (bench-scale) has been completed;
4. Candidate materials of construction for the pilot plant have been identified; and
5. The process has been adapted to solar and fusion energy and has shown good compatibility with both heat sources.

In addition to these accomplishments, there are several areas where potential process improvements have been identified which can lead to a significant increase in the thermal efficiency of the process and will also reduce capital equipment requirements drastically.

Introduction

The sulfur-iodine water-splitting cycle has been under development at General Atomic Company (GA) since 1974. The process is described by the following chemical equations:

$$xI_2 + 2H_2O + SO_2 \rightarrow H_2SO_4 + 2HI_x \qquad 370K \qquad (1)$$

$$2HI_x \rightarrow H_2 + xI_2 \qquad 393K \qquad (2)$$

$$H_2SO_4 \rightarrow H_2O + SO_2 + 1/2\ O_2 \qquad 1144K \qquad (3)$$

In these equations, HI represents the average of several HI_n compounds formed in the initial solution reaction. Separation of the H_2SO_4 and HI_x takes place under gravity, since the two acids are nearly immiscible. The upper phase contains most of the H_2SO_4, and the lower phase contains most of the HI_x.

The main attributes of the cycle are that its thermal efficiency is expected to be high (about 50%) and that it can be conducted as an all-liquid and gas-phase process, a characteristic that should give it considerable engineering advantage over any cycle requiring solids handling.

Efforts are now under way to demonstrate the use of high-temperature solar heat from central receivers as the heat source for the process. This involves conducting the high-temperature portion of the cycle during daylight and storing sufficient energy and recycle materials to run the other portions of the cycle continuously.

The development effort is under the joint sponsorship of the Gas Research Institute, the Metal Properties Council, GA and the U.S. Department of Energy (DOE) (Energy Storage Systems, and Solar Thermal Power office).

Experimental and Engineering Studies

Chemical Investigation

The Chemical investigations have established the basic chemistry for the process, developed innovative process improvements, and provided thermodynamic and kinetic information needed for process design.

Process Engineering Studies

Process engineering studies have resulted in completion of the design of an engineering flowsheet during 1979. The calculated thermal process efficiency for the flowsheet was 47%. Presently a revision of flowsheet Section III (HI Purification) is under way. Potential improvements have been identified which may increase the thermal efficiency of the total process as much as 2% and decrease capital equipment requirements as much as 40%. Since a significant amount of the total power requirements for the process are in this section, high priority is given to improvement of this part of the system.

A significant design effort has also been carried out to establish the feasibility of coupling high-temperature solar receivers with the GA process. Preliminary results indicate that the system is quite feasible. The proposed concept carries out the high-temperature portion of the process (H_2SO_4 decomposition) during the daylight and stores sufficient heat and recycle materials to run the other portions of the process continuously. The concepts of chemical heat storage (SO_2-O_2) and sensible heat storage (molten salt) were investigated. Preliminary indications are that molten salt heat storage appears to have lower cost and greater ease of operation than chemical heat storage associated with the SO_2/SO_3 reaction. However, these data are very preliminary and need to be verified by a more detailed evaluation of both concepts.

Bench-Scale Studies

Installation of the bench-scale system, which is separated into three subunits, has been completed.

Preliminary data gathering in Subunits I and II has been carried out. The main purpose was to establish engineering parameters and verify flowsheet conditions. The data will be used in the future design of a pilot plant.

Flowsheet design conditions have been verified in the bench-scale equipment, and areas where further basic chemistry investigations are needed were identified. The main emphasis of the bench-scale effort is now being placed on gathering engineering data for the flowsheet design effort.

Materials Investigation

Materials investigations are an essential part of the GA water-splitting development program. Material classes evaluated have included metals, alloys, plastics, elastomers, and ceramics of interest for hardware applications at temperatures up to 400K.

Results of the tests in the corrosive liquids of the sulfur-iodine process have allowed the identification of potential materials of construction for the pilot plant.

Summary

Development of the sulfur-iodine process at General Atomic has progressed significantly in the last two years. A process efficiency of 47% was achieved for the engineering flowsheet; the benchscale equipment for all unit operations of the process was installed; decomposition of hydrogen iodide in the liquid phase was demonstrated; and potential materials-of-construction for process scaleup were identified. Conceptual design studies utilizing solar energy as the heat source for the process indicate that such a system is quite feasible.

Acknowledgment

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SOLID POLYMER ELECTROLYTE WATER ELECTROLYSIS HYDROGEN GENERATION AND ITS ROLE IN RENEWABLE ENERGY TECHNOLOGY

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Many renewable energy sources which generate electricity are periodic in nature. Solar sources are subject to day/night cycles; wind generators are subject to wide swings in wind intensity; tidal sources cycle twice a day, and even low-head hydrosources are subject to seasonal variations. In general, however, the natural cycle of these renewable sources do not match the load cycles of their applications. This leads to periods when there is not enough power available, and periods when excess power is produced.

Therefore, in order to effectively utilize the full capacity of periodic renewable energy sources, a means is needed to either store the excess power available for use during peak load periods, or utilize the excess energy to form a fuel which could relieve the demand on non-renewable energy resourses.

The production of hydrogen by the electrolysis of water fills just such a need. Water electrolysis is the electrochemical dissociation of water into its component parts, hydrogen and oxygen, using electricity. The production of hydrogen by the electrolysis of water during periods of excess power, offers a wide range of options:

- Hydrogen can be utilized directly as a gaseous fuel. It can be transported as pure hydrogen or mixed with natural gas or SNG through new or existing pipelines.

- Hydrogen can be utilized directly as a chemical feed stock for products such as ammonia, which in turn can be used to produce fertilizer or used as an effective energy transport medium.

- The hydrogen can be used directly by industry, particularly the chemical, petroleum refining, pharmaceutical, food and metals industries. Such industries currently depend on natural gas and petroleum for over 96% of their hydrogen needs, and their need for hydrogen is expected to quadruple by the end of the century.

- Hydrogen can be stored in a variety of forms (i.e., hydride, cryogenic, high-pressure) and reconverted to electricity during peak-load periods via fuel cells or gas turbine generators. In this way, the electrolyte generation of hydrogen is equivalent to the storage of electricity in chemical form.

Indeed, the scenario for electrolytic production of hydrogen is not limited to the use of excess power from cyclic sources. In geographically dispersed, steady-state, renewable energy source applications such as Ocean Thermal Energy Conversion (OTEC) systems located far offshore, the electrolyte generation of hydrogen to produce ammonia for transport by tanker to on-shore sites not only is a cost-effective form of energy transmission, but offers the option, at dispersed on-shore sites, for either direct use of the ammonia or reconversion to electricity.

The role of electrolytic hydrogen generation in renewable energy technology

is therefore, to expand the usefulness, broaden the range of application and increase the flexibility of the renewable energy sources.

In 1975, the General Electric Company was selected by the (then) ERDA to develop an advanced water electrolysis technology based on the use of solid polymer electrolyte. This technology was a spin-off from the solid polymer electrolyte technology developed for NASA during the 1960's. Since the original ERDA contract, in recognition of the expanded use of hydrogen in the future energy picture, sponsorship of this development has grown significantly. In addition to continued Department of Energy (DOE) and General Electric sponsorship, support has been received from the Niagara Mohawk Power Corporation, the Empire State Electric Energy Research Corporation (representing eight New York state Utilities), The New York State Energy Research and Development Authority, The Gas Research Institute and The Electric Power Research Institute.

The solid polymer electrolyte technology promises higher current densities (and thus lower capital cost), higher conversion efficiencies, and improved maintainability compared with caustic liquid electrolyte electrolyzers commercially available today.

The development program is a parallel technology development and hardware scale-up effort with a goal of demonstrating a multi-megawatt hydrogen generation system in the mid-1980's. To date, cell scale-up to a 2.5 ft^2 active area has been accomplished, and multi-cell modules of 250, 500 and 2000 SCFH hydrogen output have been operating for more than 1300, 1000, and 700 hours respectively. Figure 1 shows a 2000 SCFH module containing 60 solid polymer electrolyte cells, and Figure 2 shows that module on test at GE's Wilmington, Massachusetts facilities.

FIGURE 1 2000 SCFH Solid Polymer Water Electrolysis Module

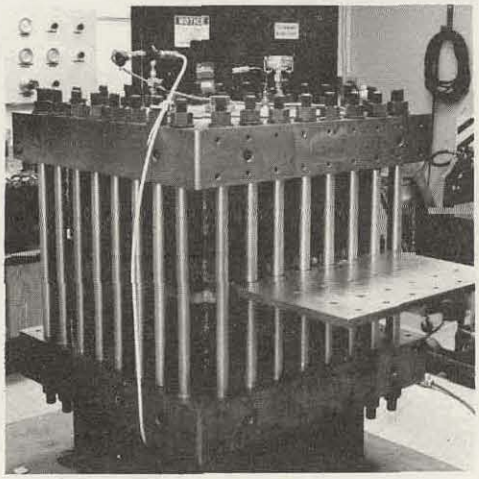
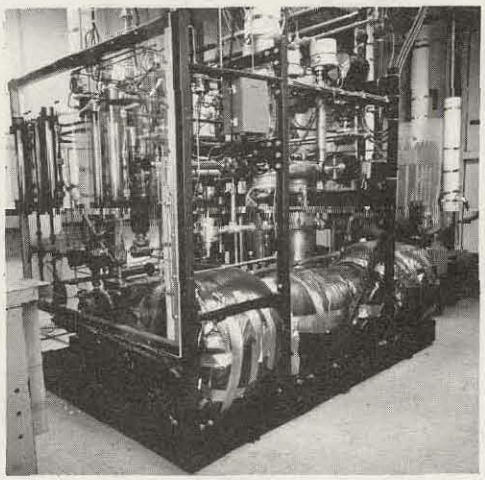


FIGURE 2 2000 SCFH Module on Test



Scale-up to a cell size of 10 ft^2 active area is in the initial stages. This cell size is aimed at module capacities in the 5,000 to 20,000 SCFH range. Multiple module systems will cover applications of 20,000 SCFH.

In addition, scale-down to a 1 ft^2 cell size is in process, aimed at smaller industrial and utility applications such as the generation of hydrogen for electric generator cooling; an application which now uses merchant hydrogen derived primarily from the reformation of natural gas.

During the oral presentation, several of the many potential applications of solid polymer electrolyte water electrolysis in conjunction with renewable energy sources will be discussed and an up-to-date status of the development program presented.

SECTION 12

SOLAR HEATING AND COOLING

SOLAR HEATING AND COOLING

Program Chairman: *Jon M. Veigel*, Solar Energy Research Institute
DOE Advisor: *Frederick H. Morse*
Overview Presentation: Wednesday, December 10, 8:30 A.M.

"New Direction in the U.S. Solar Program" 2-38
Frederick H. Morse, DOE

SESSION I: Tuesday A.M.
What Are the Opportunities?

"Selecting Effective Solar Programs: The BPA Experience" 12-1
Walter E. Pollock, Bonneville Power Administration
"Solar Commercialization Opportunities in the Northeast" 12-3
Lawrence Levy, Northeast Solar Energy Center
"Societal Scenarios as the Context for a Contemporary Energy Strategy: Implications of a New California Study" 12-5
Meir Carasso, Solar Energy Research Institute

SESSION II: Tuesday P.M.
How Good Are the Systems?

"Cost and Performance Competitiveness of Solar in Building Applications" 12-8
Lyle Groome, Solar Energy Research Institute
"Correlations of Laboratory System Performance Test Results with Field Performance of Solar Domestic Hot Water Systems" 12-10
Francis C. Wessling, Jr., Tennessee Valley Authority
"Actual Experiences with Installers, Piping and Control Systems, and Operating Personnel" ..... *
J. Pearson Richard, Heapy Associates

SESSION III: Wednesday A.M.
How Will the Industry Develop?

"Solar Industry Development in California: The Past, the Promise" ..... *
Brian Langston, Southwest Energy Management
"Solar Industry Outlook, A National Perspective" ..... *
Joseph M. Carlson, Exxon Enterprises

SESSION IV: Thursday A.M.
Is Government Help Making a Difference?

"Solar Tax Incentives, Boom or Bust" 12-12
Herbert A. Wade, Missouri Department of Natural Resources
"Solar Heating and Cooling: TVA's Experience" ..... *
Bob King, Tennessee Valley Authority
"Defining Government's Role: The Level Makes the Difference" 12-14
Janice G. Hamrin, California Energy Commission

*Abstract not available for printing in Conference Proceedings

SESSION V: Thursday P.M.
How Well Are We Now Doing?

"California Experinces in Utility Financing of Solar Water Heaters" 12-16
Leonard M. Grimes, Jr., California Public Utilities Commission
"Mid-American Commercialization Progress in the 80's" 12-18
Donald E. Anderson, Mid-American Solar Energy Complex
"How Do Present Federal Technology and Market Development Support the Business Environments?" . . . . . *
Jim Dollard, Solar Energy Research Institute

SELECTING EFFECTIVE SOLAR PROGRAMS: THE BPA EXPERIENCE

Walter E. Pollock, Chief
Branch of Conservation
Bonneville Power Administration
Portland, Oregon

The opportunities for solar depend, of course, upon who you are, how you derive your interest in solar energy, and what you are able to do. Since the public recognizes the great potential of solar energy and believes that government, utilities, and hardly anybody is doing as much as they should in utilizing solar, it is easy to allow yourself to be pushed into solar programs quickly, later discovering you are involved in an effort frought with problems. In that case, not only your own programs are set back, but also our collective efforts to foster widespread use of solar energy are potentially hurt.

The Bonneville Power Administration is a Federal power marketing administration which markets a large amount of Federally generated electricity in the Pacific Northwest (Washington, Oregon, Idaho, and western Montana). We currently market approximately one-half of the electrical power consumed in that region. Our sales are predominately to publicly owned utilities with some direct sales to industry, sales of nonfirm energy to investor-owned utilities, and sales of surplus energy over an intertie to the Pacific Southwest. In recent years, our circumstances have changed from an agency with abundant supplies of electric power to be marketed to one with less than the necessary amount to fulfill even the major part of the region's needs. We face particularly bleak prospects in the Pacific Northwest throughout the 1980's as the region's growth outstrips the capacity of existing and planned electric generating plant additions. Moreover, the high cost of new electric power generation has many people wondering whether there might not be less expensive alternatives.

While our characteristics are unique, our experience in selecting solar programs may be useful to others--particularly since we have spent substantial effort examining how we can invest in solar energy in a similar fashion to investment in central-station electricity generation.

Since we are an electricity wholesaler, our process of selecting programs begins with an examination of, first, how electricity is used in the region; and second, the areas where prospects for substituting solar energy are high. Table 1 presents a summary of electricity uses in the Pacific Northwest. An initial examination shows that residential and commercial space and water heating comprise a very large portion of total Pacific Northwest electricity consumption. Because of historic low rates for electricity in the region, the use of electricity for space and water heating

Table 1

Use	% of Total Requirements
Residential Space Heat	10
Residential Water Heat	8
Other Residential	14
Commercial Heating, Ventilating, Air-Conditioning, Lighting	12
Other Commercial	3
Industrial	39
Irrigation	4
Losses	8
Other	2

is much greater than in other parts of the country. For example, more than 90 percent of water heating is done electrically, and on the order of 50 percent of residential space heating is electric. While industrial energy consumption is the largest fraction of the total, our initial examination of this area has shown relatively small opportunities for solar utilization. Most industrial and agricultural process heat is supplied by conventional fuels, and while solar applications of this type might be important for people directing their efforts to petroleum and natural gas conservation, it is not of great interest to BPA. Thus, our solar programs are concentrating on residential space and water heating with possible expansion to the commercial sector.

All BPA's expenditures come from funds derived from power sales. Therefore, we must be reasonably certain that any activity we undertake has at least the promise of direct savings of electricity and attendant lower costs to our ratepayers. As a result, our solar programs have focused on ways in which we can invest in solar with a reasonably assured return in the form of energy savings. That is, for every program we undertake, we want to be sure that we will be buying kilowatthours at less cost than from new generating plants. As an example, assume new electricity supplies cost 6¢/kWh, and the average price paid for electricity by consumers is 2¢/kWh. We can afford to invest 4¢ for each kWh of electricity saved through a solar project. (Some might argue that we could invest the full 6¢; however, the immediate impact of a program results in 2¢ worth of lost power sales.)

Under this approach we have looked for opportunities where investment at this level would be productive. We have, for example, undertaken a program where we will contribute $700 towards the cost of a contractor-installed solar water heating system. The $700 is the computed value to us of the energy which would be saved by this system over its lifetime. We are undertaking a similar program for do-it-yourself water heating systems. In this case, we will pay slightly less, $500, since the do-it-yourself systems are generally smaller. In examining the possible application of these principles to new home construction, we are considering a program whereby we could contribute a fixed amount towards the cost of a new passive solar home. In this case, however, we are having trepidations because the analytical techniques and understanding of passive solar design has not evolved to the point where we can develop a simple formula for determining the amount of electricity savings, and, therefore, financial contribution that we could apply to homes of various types. A similar problem exists in the case of passive retrofit. While we would like very much to undertake an incentives program similar to our solar water heating program, much work is needed to develop a better understanding of the energy savings resulting from various retrofit approaches.

In essence, BPA's approach to solar programs is aimed at investing in solar applications with known electricity savings and contributing up to the amount equivalent to the value of those savings to BPA over the life of the project.

SOLAR COMMERCIALIZATION OPPORTUNITIES IN THE NORTHEAST

Lawrence Levy
President
Northeast Solar Energy Center
Boston, Massachusetts

There is little question that this country faces an uncertain future because of our current high dependence on oil, particularly foreign imports. As each day dawns, we all wonder what new crisis will erupt in this volatile world that will further threaten our national security and well being. The roots of most of these problems stem from our high use of oil, and the fact that we are running out of this resource, not only in the United States, but all over the world.

As a Nation, we are currently using about 18 million barrels of oil a day, a little less than half of which is imported. This year, we will spend about $90 billion to buy that foreign oil, and we know that the price will continue to rise. These continued expenditures have very serious effects on our balance of payments, and threaten the very political, economic and defense viability of the country. As far as the Northeast is concerned, our problem is much more serious than the rest of the Nation, because we derive much more of our energy from oil. The nine States of the Northeast, the six New England ones and New York, New Jersey and Pennsylvania import 100% of the oil we use; 37% from domestic sources and 63% from abroad. We are currently importing about 2.8 million barrels a day, and this oil is costing us over $32 billion a year which causes a tremendous cash drain on the Region and seriously affects our economy.

As a consequence, we are in a desperate race to find alternatives to our high use of oil. Solar energy represents one alternative that offers much potential for the future energy supply of the country, particularly in the Northeast. On June 20, 1979, in an important message, President Carter set a goal of a 20% contribution for solar by the year 2000. The solar options included in this goal were hydro, biomass (wood), residential and commercial heating and cooling, passive, agricultural and industrial process heat, wind and photovoltaics. Assuming a total energy usage in the year 2000 of from 95 to 100 Quads (10^{15} BTU's), and excluding hydro, the Northeast's share of the 20% goal based upon percentage of total population (as a first approximation) would be 3.12 Quads. The calculations that I performed on the amount of hardware and material that would have to be in place in the year 2000 show the immense proportions of the job that must be done to meet the goals. The results for the Northeast are shown below:

BIOMASS - 41 million cords of wood would have to be burned in the year 2000 to achieve 1.2302 Quads. RESIDENTIAL HEATING & COOLING - 3.007 billion square feet of collectors would have to be in place in 6,014,993 installations to achieve 0.2278 Quads. PASSIVE SOLAR DESIGN - 2.797 billion square feet of glazing material would have to be in place in 13,986,000 installations to achieve 0.2278 Quads. AGRICULTURAL & INDUSTRIAL PROCESS HEAT - 3.257 billion square feet of collectors would have to be in place in 651,356 installations to achieve 0.5920 Quads. WIND - 162,101 Wind machines would have to be in place in a mix of sizes from 5 KW to 1 MW to achieve 0.3872 Quads. PHOTOVOLTAICS - 3.417 billion square feet of solar cells would have to be in place to achieve 0.2278 Quads.

While the investment in 1979 dollars is very large to implement these solar options over the next twenty years, their use would save the equivalent of 520

million barrels of oil in the year 2000; and, over the next twenty years, 3.29 billion barrels of oil equivalent would be replaced--a very substantial quantity. The Northeast Solar Energy Center (NESEC) is now in the process of refining these numbers to include many other pertinent factors. It will be a mammoth task to achieve these goals starting from where we are today, but I am convinced, however, that it will be possible to reach this objective given the proper national priorities and resources. The Regional Solar Energy Centers, of which there are four nationwide, will play an important part in the achievement of the solar goals. Their creation represents a new and novel approach on the part of the government to help it achieve its objectives. The mission of NESEC is to be the Department of Energy's lead institution in the nine states of the Northeast to accelerate the commercialization of solar technologies and conservation integral to solar applications. Our activities are complementary to the Solar Energy Research Institute in Colorado whose principal mission is research, development and demonstration of solar technologies.

In carrying out our mission, we work with the private sector to develop solar options; we work with our respective States in overcoming legal regulatory and institutional barriers to solar implementation, and we are active in convincing the consumer that solar energy represents a viable option that should be utilized, particularly in the Northeast where energy costs are very high. Our program at NESEC involves activities in Planning, Program Management, Systems Analysis, Market Development, Information and Education, and Technology Development. We provide well-directed and managed programs in business and financial services, industrial liaison, information dissemination, public affairs, consumer services, barrier reduction and incentive development, technical assistance, education, and demonstration support. We publish a monthly newspaper, called NESEC Update, which we mail to about 40,000 people. We also have a growing library on solar energy which is the best in the Northeast. All of our services are provided free-of-charge to those who are interested in solar energy.

We are confident at NESEC that our current programs can bring about the desired result of solar commercialization. We have already achieved a number of milestones and have seen evidence that our presence has been a positive force in the Region, and that many solar activities would not have taken place without our active stimulation of the process.

The program to develop alternatives to our use of oil, particularly in the Northeast, must be viewed with the highest priority. This Nation has the technical and management skills to reach the goals, but we must somehow bring to bear those skills of invention, innovation and entrepreneurship that made our country great in the first place. While there are many challenges connected with alternative energy development, there are also tremendous opportunities, and we all have a personal stake in the success of the effort.

SOCIETAL SCENARIOS AS A CONTEXT FOR CONTEMPORARY ENERGY STRATEGY: IMPLICATIONS OF A NEW CALIFORNIA STUDY[1]

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Golden, Colorado, U.S.A.

BACKGROUND AND MOTIVATION

In the long run, energy requirements will depend on the choices people make about where and how to live and work, what to buy, how much to travel, and so on. People make these choices on the basis of cultural and other values, preferred lifestyles, economic circumstances and age, choosing from the options, both technological and societal, that they perceive are available. Almost without exception, current assessments of future energy requirements are based on the assumption that lifestyles will remain much the same in the future as they are in the present. Yet lifestyle choices have been changing, and will probably continue to change (e.g., "voluntary simplicity" and, more recently, the trend toward smaller, gasoline-conserving cars).

In addition, the ongoing intense debate over energy conservation, production, and import issues have led us to seek an increasingly comprehensive view of the links between alternative energy strategies, resource scarcity, a healthy economy, environmental consequences, dependence and vulnerability, and, ultimately, a sustainable future.

Motivating this California study was the need to guide state energy policy by assessing the energy related implications of choices individuals make regarding their lifestyles, and, simultaneously, by developing satisfactory systematic means for illuminating the relationship between these choices, appropriate energy strategies, and the sustainability of the composite society/economy scenarios which emerge.

FINDINGS

The study demonstrates the significance of beginning energy assessments with assessment of societal and lifestyle trends. The need for such explorations has become particularly apparent in light of evidence of voluntary changes in values, as well as due to more recent indications that lifestyle changes may be an inevitable consequence of global resource, environmental and population stresses.

A major finding of the study is that a scenario (I) based on the assumption that lifestyles in the future will remain much the same as they are in the present is dependent for its viability on the availability of increased supplies, the occurrence of technological breakthroughs, and the overcoming of conflict and enforcement of policies by increasingly bureaucratized and centralized decision making processes. The alternative scenario (II) explored during the study involves modest changes in styles; nonetheless, it avoids some of the resource and environmental difficulties of the first scenario, has a lower conflict potential, is more flexible in dealing with unanticipated changes, and involves more local decision-making.

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[1] "California Energy Futures: Two Alternative Societal Scenarios and Their Energy Implications". Directed by the author for the California Energy Commission and performed by SRI International, February, 1980

Some Scenario Highlights	1975	2000 Scenarios I	2000 Scenarios II
Per Capita Income ($1975)	6,751	11,990	9,500
Per Capita Primary Energy Consumption (10^6 Btu/yr)	264	263	180
Primary Energy Supply (10^{12} Btu/yr)	5,590	7,800	4,750
Non-renewable	5,400	7,390	4,200
Renewable	150	410	550
Primary Energy Consumption / Personal Income ($\frac{Btu}{\$}$)	39,105	21,935	19,000

OTHER FINDINGS

- Conservation and saturation effects result in a reduction of energy consumption per dollar of personal income in either scenario
- The modest changes in lifestyles in scenario II cause a reduction of 20% in energy requirements by the year 1990, and 31% by 2000 as compared to scenario I.
- From a perspective of 75 years, a supply oriented energy strategy such as is required by scenario I is viable only if major breakthroughs occur, such as in fusion. If there is not a suitable technological breakthrough, scenario I is headed for some form of collapse in the latter part of the 21st century.
- Due primarily to the increasing scarcity, costs, scale, and risks of nuclear energy and fossil fuels, an energy strategy based on conservation and renewable sources is much more flexible and resilient than one which relies on increasing supply of conventional sources (by conservation is meant both efficiency improvements and reduction of waste, and a willing, voluntary attitude to conserve).
- While the existence of an imminent energy crisis may be arguable there exists an imminent decision crisis on energy strategy. Policy guideline: act to hasten the choice of an energy strategy through educational efforts and through contributions to the public dialogue.

METHODOLOGY

The study methodology represents a break with conventional energy forecasting and energy scenario analysis by developing two future societal scenarios, where each scenario is a consequence of, and is consistent with, the aggregate of explicit individual choices about values and lifestyles, as well as an explicit statement about the assumed global and national context. Analytical methods and models were used to simulate quantifiable relationships in each scenario. The basic approach consisted of selecting two central societal themes, one for each scenario, and deriving from these, in as explicit a manner as possible during the study, sufficient quantitative definition to deduce, in sequence: population, demographic and lifestyle indicators, consumption and transportation requirements, economic and industrial activity, and on the basis of these, to estimate energy requirements. Two energy supply scenarios were then developed for each demand scenario in a manner consistent with the societal themes of the scenarios. Finally, the policies required to implement each of the scenarios were examined. The characteristics of these policies and the institutions required for bringing them about were used to derive an overall assessment about the kind of society implicit in each scenario.

The study team consisted of people with experience in developing societal scenarios with a long-term future orientation, economics, energy systems analysis and policy analysis. While the methodology described above implies a linear process of information flow during the study this is an over-simplification. Major feedback loops were developed to reconcile inconsistencies. The scenario themes, therefore, are consistent with the scenarios which finally evolved, and at times are considerably different from the original ones used to begin the study.

SUMMARY OF SCENARIO THEMES

Scenario I	Scenario II
• "More is better"	• "Doing with less"
• Striving for affluence dominant	• Increasing appreciation of non-material values
• "Man over nature"	• Ecological ethic
• High economic growth	• Slowing economic growth
• Increasing regulation	• Increasing local choice

A generally benign global setting was assumed. No world war, no dramatic changes in climate, no environmental threat or epidemic, no interruption of international commerce and no collapse of political, economic, or social systems were assumed. It was also assumed that social and consumer values will not change in the future any more drastically than they have changed in the past 75 years.

COST AND PERFORMANCE COMPETITIVENESS OF SOLAR IN BUILDING APPLICATIONS

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Over the past year, a series of studies has been performed to compare active solar system performance and economics against the competing conventional systems in each building application. The objective of this work is to establish cost performance goals for solar systems and monitor progress towards these goals. The effort to date has included the establishment of a standard set of analysis assumptions and a consistent framework for performing comparative analyses. These consist of standard locations and weather sets, standard building descriptions, sizing techniques, costing methodology, and economic assumptions. (1,2). A survey was made of simulation tools available (3,4) and the TRNSYS computer code was chosen as the basic tool for this series of studies. A residential load model was developed as a component of the TRNSYS code; and commercial building load tapes, formatted as inputs to TRNSYS, were generated using the BLAST program. (1)

To date, the comparative analyses performed include:

- A comparison of conventional and solar domestic hot water (DHW) systems
- A comparison of six generic solar SHW system configurations
- A comparison of series and parallel solar heat pump systems to conventional heating and cooling systems for residences
- A comparison of Absorption and Rankine cooling systems for commercial applications

Solar Water Heaters

As part of a larger study to assess solar DHW products and their competitive standing with the conventional water heaters (5), performance and economic analyses were performed using five generic solar system configurations and two conventional systems. Four cities were chosen to give a range of climate but also represent major market areas for solar DHW systems. TRNSYS was used to simulate system performance for two cities with TMY weather data available (Washington,D.C. and Phoenix) and FCHART was used to determine system performance in the remaining cities (Los Angeles and Denver). Five solar systems were modeled on representative commercial systems and included four systems with flat plate collectors: direct draindown, direct drain back, direct recirculation, indirect; and one system using an evacuated tube collector. All systems used a two-tank arrangement. Both a monthly cash flow and a present value analysis were performed. Three financing schemes were examined and two tax credit scenarios including an instant tax credit, where the tax credit is subtracted from the purchase price. Results show that solar systems have lower average monthly costs than electric water heaters in all four cities with a 40% tax credit and are even competitive with gas water heaters if an instant tax credit is assumed.

A separate study of six generic system configurations for solar water heaters (6), based upon actual performance data, drew the following conclusions: the thermosyphon is the most cost effective solar water heater configuration, but at the present is limited by lack of reliable freeze protection; air-collector water heaters are the least cost effective; and direct systems are more thermally efficient than indirect systems.

SOLAR ASSISTED HEAT PUMPS

A detailed study was performed comparing several solar assisted heat pump configurations, against conventional systems (including a conventional heat pump). (2) Four combinations of series and parallel configurations with both air and water collectors were examined. Using TRNSYS, performance was simulated for three cities: Washington, D.C., Fort Worth, and Madison. A sizing methodology for the collectors was developed to yield a minimum system cost per unit of energy displaced. All systems were designed and operated to provide a specified level of thermal comfort. The results of the analysis showed that, although solar heat pumps save substantial amounts of purchased energy, they are not economically competitive on a life cycle cost basis with conventional heat pumps at any collector cost. An additional sensitivity study looked at variations in component cost and performance. The results showed that only a 75% tax credit would make solar heat pump systems competitive with conventional heat pumps, although decreasing collector costs while increasing collector and compressor performance would probably make them competitive under the tax credit found in some states today (e.g. Colorado with a combined credit of 70%).

COOLING SYSTEMS

Preliminary results of an analysis of Absorption and Rankine cooling systems for commercial buildings (25ton size) show that Absorption systems are currently more cost effective than Rankine systems, however, the data used in this study was very "soft". Work is currently underway to compare residential and commercial solar cooling systems with conventional systems and generate cost/performance goals. It is generally accepted that solar cooling systems for residential applications are not currently economically or technically viable.

CONCLUSIONS

The studies to date show that active solar water heaters can be very competitive in the marketplace, even against gas water heaters. The cost effectiveness of active space heating systems, particularly solar assisted heat pump systems has not been proven. These systems will have a difficult time competing against conservation measures and passive solar systems. Solar cooling systems are still in the development stages and may be marginally cost effective when combined with heating systems for commercial buildings, but are not competitive in the residential market.

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6. Farrington, R.B., Murphy, L.M., Noreen, D.L., A Comparison of Six Generic Solar Domestic Hot Water Systems, SERI/RR-351-413, April 1980.

CORRELATIONS OF LABORATORY SYSTEM PERFORMANCE TEST RESULTS WITH FIELD PERFORMANCE OF SOLAR DOMESTIC HOT WATER SYSTEMS

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In November 1979 the Tennessee Valley Authority (TVA) began the evaluation of solar domestic hot water (SDHW) systems. Approximately 90 systems were proposed by manufacturers. Analyses of the proposals resulted in 32 systems being selected for thermal performance testing. These were tested according to a task document (1) written by TVA and NASA Huntsville. The document was a revision of the original ASHRAE 95P test standard (2) which has recently been changed to incorporate many of the features of the TVA test document. The new ASHRAE standard (3) and the TVA test document differed chiefly in a TVA load management requirement, the energy input hardware configuration, and the interpretation of data. The testing and engineering evaluation resulted in 11 systems being selected for our Nashville and Middle Tennessee installation program.

In TVA's original testing, an energy multiplier (E.M.) parameter was defined as the thermal load delivered divided by the electrical energy work input. This parameter was basically a coefficient of performance of the SDHW system. Using the energy multiplier parameter, a fractional energy savings (FES) was derived from the following equation: FES = 1.0 - 0.8/E.M. The 0.8 corresponded to the energy multiplier of a conventional, non-solar, 52 gallon water heater which included losses calculated from data obtained from the National Bureau of Standards.

The FES parameter and the SDHW system installed cost (IC) was then used to calculate a cost benefit ration. The cost-benefit-ratio equation is:

$$CBR = \frac{(IC)\ (0.6)\ (0.8)}{(7300)\ (FES)\ Q_L}$$

Where 0.6 is a federal tax credit coefficient, 7300 is the number of days in 20 years (the loan repayment period), and $0.8/Q_L$ is the reciprocal of the amount of electrical work input estimated to be required by a conventional, non-solar water heater to produce the thermal load Q_L. The units of this CBR are the cost per unit energy delivered by the SDHW system (¢/kWh). The quantity 7300 (FES) $(Q_L)/0.8$ is the replaced electric energy delivered by the SDHW system for one year, and is given in Table 1 along with system characteristics and the CBR.

The systems are installed in a TVA test facility and their performances are measured over a period of time. A measurement of their performances under actual weather conditions are to be presented to correlate the systems' field performances under actual weather conditions with their performances in the laboratory.

1 - Tennessee Valley Authority, Test Requirements, Residential Solar Hot Water Systems, October 1979.
2 - Same as 3 except Draft, April 15, 1979.
3 - ASHRAE Standard 95P, Method of Testing to Determine Thermal Performance of Packaged Solar Domestic Water Heating Systems, Second Draft, April 15, 1980.

	Gross collector area $m^2(ft^2)$	Number of collectors	Heat transfer fluid[1]	Type[2]	Number of tanks	Solar tank size m^3(gal)	Booster tank size m^3(gal)	Absorber Plate[3]	Glazing[4]	Annual[5] kWh delivered by solar	Cost Benefit Ratio ¢/kWh
Grumman (one tank)	5.92(63.7)	2	E	CL	1	.31(82)	NA	S	IG	2217	4.06
Grumman (two tank)	5.92(63.7)	1	E	CL	1	.31(82)	.30(80)	S	IG	2312	4.16
ITC Solar	5.325(57.3)	3	W	DB	1	.30(80)	NA	S	IG	2683	3.03
Northrup	.239(77.9)	3	E	CL	2	.31(82)	.20(52)	N	IG	2329	4.28
Rheem Rudd	5.13(55.2)	3	W	DD	1	.31(82)	NA	S	IG	2888	3.53
Solar One/4	6.08(65.4)	4	P	CL	2	.31(82)	.30(80)	N	K	1880	3.81
Solar One/5	7.6(81.8)	5	P	CL	2	.31(82)	.30(80)	N	K	2276	3.56
Solar Thermal Systems/2	4.216(45.4)	2	W	DB	1	.45(120)	NA	S	IG	2315	3.47
Solar Thermal Systems/3	6.342(68.0)	3	W	DB	1	.45(120)	NA	S	IG	3014	3.08
Solar Unlimited	7.16(77.0)	2	0	CL	2	.30(80)	.31(82)	N	IG	2086	4.68
Sun Works	5.772(62.1)	3	P	CL	2	.30(80)	.20(52)	S	IG	1968	4.73

1 - 'W' is water; 'P' is propylene glycol/water; 'E' is ethylene glycol/water; '0' is silicone oil
2 - 'DB' is drain back; 'DD' is drain down; 'CL' is closed loop
3 - 'S' is selective; 'N' is non-selective
4 - 'IG' is single-glass; 'K' is single-polyester resin
5 - These estimates are based on TVA system tests and will vary depending on usage patterns and weather conditions. A conventional system would deliver approximately 4560 kWh annually under these test conditions.

SOLAR TAX INCENTIVES, BOOM OR BUST

Herbert A. Wade
Missouri Dept. of Natural Resources
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Although income tax credits remain the most popular solar incentive given by state governments, there is a wide variability in their apparent effectiveness for different states. Some states such as Kansas have had virtually no response while others such as Arizona have spent millions in credits to their citizens. In trying to account for these remarkable differences in response it is necessary to examine the problems with tax credits and how they interact with the rest of the socio-economic process.

First, we should list basic problems with tax incentives as enacted in most states. Probably most important is the fact that their face value is considerably higher than their real value. This is due to (1) state tax credits are taxed by the Federal government at rates varying with income--often from 20% to 30%; (2) credits can not be received until returns are processed, a three to fifteen month time period during which interest is being paid on capital; (3) at the state level, allowed credits often exceed total tax liability and require carryforwards further delaying actual consumer receipt of the money and adding interest costs. For states with modest taxes, a 25% tax credit on an $8,000 system may have its real value reduced to less than $1,000. Other difficulties are (1) difficult processes for claiming the credit--some states require the submission of system plans for state review, complex reporting forms or forms that are not part of the forms package provided the taxpayer; (2) poorly written definitions of systems which can qualify; (3) a general lack of understanding of the credits by revenue service offices, tax consultants and even the sellers of solar equipment. Most of these problems have a simple solution: rebate the money at or at least near the time of the sale and do a good job of writing and publishing the regulations relating to the credits. As an example, New Mexico has done both. Her 25% tax incentive is a rebate, not a credit. No matter what the individual's tax liability is for the year, a solar claim is paid in full upon receipt of the claim at tax reporting time. While there is still a wait, at least carryforwards are not needed. The regulations for the New Mexico tax credit are clear, well documented and publicized. Yet, New Mexico has not had a markedly different solar growth curve from that of similar states with poorer or no tax credits. For some explanation, socio-economic factors must be examined.

Perhaps the very most basic problem with state income tax incentives is that they only help overcome economic barriers. In most states, economics is not the primary barrier to solar implementation at the consumer level. More basic is the lack of trained and experienced installers, servicemen and vendors. Few persons

are willing to commit to the installation of a major appliance unless they have confidence in the dealer, installer and service organization. Except in a few metropolitan areas of the country, there is essentially no solar business structure and purchasers are not able to scan the yellow pages, pick up the phone and be reasonably confident that expected standards of quality of product and service will be forthcoming. The simple increase of consumer demand for solar products cannot, in the short term, increase the level of competency of the industry. In fact, strong demand increases, such as that supposed to be provided by large tax credits, tend to seriously reduce consumer confidence in solar since the pool of experienced businesses is so small that the rapid growth of demand can only be accommodated by the influx of large numbers of poorly qualified individuals.

A further reduction in the economic effect of tax incentives is related to the increase in price of solar equipment resulting both from increased demand without increased supply and from the extra costs borne by the manufacturer to qualify products for the tax credit. In Arizona, for example, prices of solar equipment have risen faster than inflation when examined over 1975 to 1980. A noticeable increase in price for several Arizona dealers followed enactment of the state's powerful tax credit.

If the increase in demand is permanent, these problems are temporary. But in fact, most tax credits do not encourage a strong business committment to solar for the long term. With few exceptions, the credits end abruptly rather than gradually. For the solar businessman, this can be interpreted to mean an equally abrupt reduction in demand. That, of course, is not very conducive to long term investment and committment to solar. Arizona and, more recently Michigan, have included graduated reductions in the credits to make the transition from government subsidy to free-market pricing less of a problem.

To date, eighteen states have passed some form of income tax incentive legislation. Only Arizona and California have data which clearly shows significant demand increases following passage of the tax credit. Of the other states, a number have no data. Either the law is too new or else no mechanism was provided for examining solar growth. On the basis of other reporting systems, such as the SEIA and government surveys, nothing indicates that the tax credits have had any significant impact. Indeed, Florida and Hawaii have shown much more rapid growth rates without these incentives than have almost all the other states with income tax credits (Hawaii's tax incentive is too new to have affected these growth patterns).

If there is a correlation between government policy and solar growth, it is in the level of services provided all sectors of the solar community--business, financial and consumer. Arizona, Florida, California, and other states which have greater than average solar growth rates also have much greater than average budgets for information, grants, technical assistance and those other services necessary to raise the solar consciousness of the business community as well as the consumer. In short, their programs are more balanced.

DEFINING GOVERNMENT'S ROLE: THE LEVEL MAKES THE DIFFERENCE

Janice G. Hamrin
Davis, California

Many optimistic projections have been made for meeting our energy needs through the use of renewable energy. However, realizing anything near the potential which exists requires an extremely effective implementation program and a high degree of cooperation among federal, regional, state and local government and the private sector. Unfortunately there has been frequent overlapping of programs, and duplication of efforts which result in a waste of resources, program failures and a loss of public confidence. However, there has been no concensus about the optimum roles for the various branches of government. Solar heating and cooling technologies have been included in a variety of governmental programs which provide valuable experience about the most effective roles for the various levels of government in renewable energy implementation. This paper outlines some of those roles and provides suggestions for how and where government might make a difference.

The major areas of governmental involvement include: Research, Development and Demonstration; Barrier Identification and Removal; Information Dissemination; Incentive Programs; Consumer Protection and Regulatory Programs. Governmental resources are limited but the vast amount of work which can and should be done to assist in the development of renewable energy technologies begs for a more systematic and coordinated approach to the division of governmental labor than has been shown up to now.

Research, Development and Demonstration: Basic research, development and demonstration is very expensive. The federal government is the only branch which has sufficient funds to support this activity. As a result most research and development has been done by the federal laboratories and/or under federal grants to large research firms. Research and development on applications appropriate to regional and local needs should be coordinated and possibly cosponsored by state energy offices. Such offices can also screen applicants for federal demonstration monies to encourage the funding of projects most appropriate to their area. A problem develops when demonstration projects are funded which are not cost effective or appropriate for the needs of the area in which they are located. Another problem involves the movement of a technology from RD&D to full scale commercialization without sufficient transition time for infrastructure development. This can result from inadequate coordination between programs at different levels of government.

Barrier Identification and Removal: Identification of technical, economic and institutional barriers to widespread commercialization frequently begins in a generic sense at the RD&D stage. However, some of the most critical institutional barriers can occur at the state and local level. The federal government can provide consciousness raising and the legitimizing of a technology along with funds for specific studies. The state can identify state and local barriers, pass legislation prohibiting or requiring practices which influence the successful implementation of a technology -- an example being California's solar access legislation which does not try to write a statewide solar access law but encourages local government to do so.

Information Dissemination: This category includes everything from public information and outreach to professional training programs, infrastructure development and other technology transfer activities. At issue is the need to maintain consistent credible and accurate information while tailoring such information to the diverse needs of different people and climate zones throughout the country.

Federal agencies and labs can provide basic technical information while serving as a major source of funds for regional and local information centers. However, information dissemination is more than just sending out written reports and pamphlets. Effective programs require people who are knowledgeable about the specific needs and problems of the individual or group seeking assistance. Local programs supported by credible, more centralized data sources can be the most effective vehicle for general public information dissemination. They can supply specific details, examples and if necessary, personalized assistance. State or regional programs can provide guidance, consistency and basic information and by providing or sponsoring professional training programs.

Incentive Programs: Most incentive programs have their major impact at the federal level because changes in federal tax and accounting practices have a much larger effect than do changes on the state level. Nevertheless, individual states have created models for incentive programs that are later adopted at the federal level. In this way congress is able to benefit from the experience gained through local examples.

Consumer Protection: Consumer protection activities should primarily be conducted at the state level to ensure consistency and to avoid a patchwork of conflicting and/or overlapping local efforts. State consumer protection programs include licensing, warranty assurance, inspections, complaint mediation and so forth. Testing and certification programs because of their expense and general applicability can be better handled through a national program. National standard setting is more difficult because of the diversity of conditions and needs. But minimal standards can be set which can then be supplemented where appropriate to satisfy state concerns and conditions.

Regulatory Programs: One of the most important advantages of state or local regulations over federal is that they can be tailored to meet specific needs and conditions. Because local regulations are usually easier to modify than are state or federal ones, they can be more innovative and flexible if changes in technologies, materials or techniques develop which offer a more effective means of reaching the goal. However, depending upon the type of regulations, a desire for consistency usually pushes toward state level regulations modelled after local programs.

The federal government is best at setting national goals and guidelines and passing enabling legislation which establishes new programs and direction. They also are the major source of funding and provide basic technical assistance and information. The federal government also plays a key role in RD&D and incentive programs. State and regional programs can provide coordination and planning, can develop applications of technologies appropriate to state and local needs, can provide technical assistance specific to regional and local needs and can develop strategies for increasing the rate of implementations of a technology.

Local activities are the key to effective implementation. Local government and community groups have a basic information network and knowledge of their people which allows them to mobilize human resources at a level to provide specific assistance. Commercialization programs should be designed by and for local use.

CALIFORNIA EXPERIENCES IN UTILITY FINANCING OF SOLAR WATER HEATERS

Leonard M. Grimes Jr.
Commissioner
California Public Utilities Commission
San Francisco, California, U.S.A.

The California Public Utilities Commission commenced a study of low-interest, long-term financing options for solar water heating in April, 1979. The proceeding, Order Instituting Investigation 42 (OII-42), has now covered 50 days of hearings with over 100 exhibits and 5,500 pages of transcript. Participation by interested parties has been the broadest in the history of the California Public Utilities Commission and has developed what is probably the most comprehensive record on solar financing options.

Following a report to the Legislature, an interim order to four major investor owned utilities was issued on January 29, 1980. The order included findings that solar water heating is or will shortly become cost effective for the customer in most applications; that it is vital to resolve nagging questions about the market viability of solar water heating; and that there are three principal barriers to more rapid implementation of solar water heating: 1) High initial cost, 2) Lack of consumer confidence, and 3) Inadequate information.

The utilities were ordered to submit proposed large scale demonstration programs addressing these barriers. Hearings on these and other proposals have concluded and a decision is pending. Therefore, general comments rather than conclusions are offered in this abstract.

LEADING FINANCING OPTIONS

1. Free market: Too costly to the consumer, does not reflect advantages of solar to society, would make solar the only unsubsidized energy resource.

2. Tax credit: Federal (40%) and state (additional 15%) credits available, have not adequately accelerated the market, clear discrimination against those with incomes below $15,000/year.

3. Tax credit with rebate: Not currently available, nearing final legislative approval in California (A.B. 2036), would ameliorate discrimination based on income.

4. Solar Bank (S. 932): Complicated application relying on means test with three levels, causes loss of federal tax credit, only consumer protection measure is a weak warranty.

5. Secondary market for solar loans: Could stimulate conventional financing institutions to make more solar loans, existing secondary institutions (Freddie Mac, Fannie Mae, and Ginnie Mae) have not been active, a new institution (Sunny Mac) has been proposed to deal exclusively in solar loans.

6. Direct utility loans: Offered at reduce interest rates and attractive payback terms, has been one of two key options on which the California Public Utilities Commission has focused its study. Can be targeted to specific areas, an easy to understand incentive, no credit-worthiness problems, not dependent on fluctuations in interest rates or availability of funds at conventional institutions. May offer an excessive incentive, requires additional bureaucracy in the utilities, higher cost than some other options. May be necessary to truly stimulate solar implementation.

7. Utility credits: The second option on which the CPUC has focused; can be provided as a lump sum payment, annual payment, quarterly or monthly payment, or period credit against the utility bill. May be lower cost than utility loans, does not create new utility competition for conventional financing institutions, provides incentives for consumers who prefer to pay cash. Dependent on willingness of conventional institutions to make solar loans, may discriminate against consumers who cannot qualify for loans at a bank or have no banking relationships, no ability to target to specific areas.

A final order is likely to be issued prior to the conference. The formal presentation will discuss California Public Utilities Commission resolution of financing issues, consumer and industry response to the order, and our future expectations.

MID-AMERICAN COMMERCIALIZATION PROGRESS IN THE 80's

Donald E. Anderson, Director
Mid-American Solar Energy Complex (MASEC)
Minneapolis, Minnesota, U.S.A.

The MASEC Center is located in Minneapolis and is one of four Regional Solar Energy Centers in the United States, funded by the Department of Energy and charged to accelerate the use and commercialization of solar energy and conservation related to solar applications. We presently have a staff of approximately 75 full-time people and work directly with citizen advisory groups and state energy-related agencies in the 12 states which are in our Region. In each state, we have Solar Offices affiliated with the State's Energy Office. Furthermore, MASEC's Board of Directors, nominated by the Governors of the 12 states, have reviewed and endorsed our current plans and goals for helping meet the Region's energy needs now and in the future.

The 12 mid-American states (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North and South Dakota, Ohio and Wisconsin), have in total almost one-fourth of the United States population (58 million people) and consume one-fourth the fuel (19 quads of 68 quads in 1975). They are atypical in demand for fuels for space conditioning (in 1975, only two of the 12 states were net exporters of energy). The Region as a whole imported 26 percent more energy from outside the Region than the United States imported from outside its national boundaries! They are atypical in focus on agriculture. The Region consumes approximately 50 percent of the total national energy used in the agricultural sector. It produces over 80 percent of the nation's corn and over half the nation's wheat.

All of the people in the MASEC program see as an achievable goal, a 26 percent saving on our Region's fossil fuel needs by the year 2000 provided we undertake now an active program stressing renewable energy and conservation.

The mid-American regional plan for commercialization of renewable energy and conservation actions postulates that the regional solar industry can attain a seven quad goal (of a projected total requirement for 27 quads) in fuel savings by the year 2000. Our objectives include:

- 40 percent of all new housing after 1985 will be designed to use 80 percent less energy (2.5 Btu/ft^2-degree-day in 1985 rather than 12.5 Btu/ft^2-degree-day characteristic of code-built homes in the Region today). In 1990, 70 percent of all housing will reach this goal and 80 percent in 1995.

- 50 percent reduction in fuel requirements in all other structures.

- 100 percent energy independent farms.

- 10 percent fossil fuel reduction used in transportation.

- 50 percent reduction in industrial processes with temperatures below 350°F.

How are we trying to attain these goals?

We have at our disposal an outstanding group of dedicated staff members at MASEC and citizen advisory groups and State Solar Officers (SSOs) working with us. In addition . . . and no less important . . . regional business people, labor leaders, educators, market experts, technologists, architects, engineers and builders, bankers, appraisers and community organizers have been very supportive of our efforts.

Our most widely publicized commercialization project has been the Solar 80 Project. Solar 80 homes are designed to utilize passive solar design approaches and, as a consequence of the integrated application of conservation and solar features, to save 80 percent fossil fuel energy for heating. As an example, the house in Minneapolis was opened to the public: the first weekend 2,000 persons toured it; it sold in one week at the full asking price. As of mid-August (the date of writing of this publication), seven of our regional Solar 80 homes have already been built and four sold . . . one within six days of going on the market, one within eight days and one while still on the architect's drawing board!

While the Solar 80 project is still our most highly visible effort, other equally important undertakings are actively moving ahead.

In 1979-80, our State Solar Office program conducted 272 workshops in our 12 states with over 20,000 people attending. Information dissemination on all aspects of solar application numbered over 1.7 million. The 12 states held 670 energy fairs, displays and tours for 840,000 participants. Information was developed and provided for 121 libraries. The SSOs made 342 speaking appearances before 18,720 people and there were 64 media activities viewed or read by 552,100 people. In total, our SSO program in 1979-80 reached approximately four percent of the decision-making members of a total population of 58 million persons!

What is the implication of these successes? If we achieve our goals, what does this mean in terms of employment and new business opportunities, let alone greater energy efficiency? Many recent studies, such as the report of the Subcommittee on Energy of the Joint Economic Committee of the Congress and a second report at the Harvard Business School, demonstrate the long-range goals for an aggressive solar program. A vigorous program in renewable energy and conservation means over two million new jobs by 1990. In order to accomplish this, small business involvement will be critical because, in my opinion, it is an industry which will be small and decentralized. The integrated impact of such an industry is <u>not</u> small: in our 12-state Region, the projected sales by the year 1990 might reach some $7.5 billion, and new venture capital requirements might be some $1.5 billion per year. New primary jobs are projected at 239,000 in the Region; in a very real sense helping to make the North Central States more of an "Island of Energy Self-Sufficiency."

SECTION 13

REGIONAL ENERGY PLANNING

REGIONAL ENERGY PLANNING

Program Chairman: *Robert Odland,* Solar Energy Research Institute
DOE Advisors: *James Quinn and Mary Glass*
Overview Presentation: Tuesday, December 9, 1:30 P.M.

"Six Fallacies That Impede Planning for Regional Renewable Energy Systems" 2-21
Dennis L. Meadows, Dartmouth College Resource Policy Center

SESSION I: Tuesday A.M.
Renewable Energy Planning for Island Communities

"Sardinia Energy Planning" 13-1
Andrea Ketoff, Lawrence Berkeley Laboratory
† . . . . . *
Jeffrey Dellimore, Caribbean Development Bank
"Renewable Energy Planning for Southern USA, Puerto Rico and Virgin Islands" 13-3
Juan A. Bonnet, Jr., Center for Energy and Environment Research, Puerto Rico, and *Barry Graves,* Southern Solar Energy Center

SESSION II: Tuesday P.M.
Fundamentals of Regional Planning for Renewable Energy

"Environmental Aspects of Regional Planning for Renewable Energy" 13-5
John P. Holdren, University of California at Berkeley
"The Hawaii Integrated Energy Assessment" 13-7
Jerome M. Weingart, Lawrence Berkeley Laboratory, and *Justus Muller,* State of Hawaii Department of Planning and Economic Development
"'Appropriate Bureaucracy' for Renewable Energy Development: The Role of Sub-State Regions, Counties and Units of Local Government" 13-9
Clara G. Miller, Consulting Planner, New York
"Implementation of Renewable Energy Technologies in the Face of Institutional Constraints" 13-11
Eliot Taubman, Institute for the Study of Human Issues

SESSION III: Wednesday A.M.
Renewable Energy Planning for Large Regions

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Meir Carasso, Solar Energy Research Institute
† . . . . . *
Fred Greenman, New England Power Company
† . . . . . *
Jean Solari, Tennessee Valley Authority
"Key Factors Affecting Regional Planning for Renewable Energy Technologies" 13-13
Edward E. Johanson, JBF Scientific Corporation
"The New England Sustainable Energy Project" 13-15
Abbie C. Page, The MITRE Corporation
"The Value of Dispersed Intermittent Electricity Generation" 13-17
Clark W. Bullard, University of Illinois

†Title of paper not available for printing in Conference Proceedings
*Abstract not available for printing in Conference Proceedings

SESSION IV: Wednesday P.M.
Controversies and Issues in Renewable Energy Planning

† ..... *
Gerald S. Leighton, DOE

† ..... *
Robert Hemphill, Tennessee Valley Authority

"Low Energy Futures for the United States" 13-19
Dick Holt, DOE

† ..... *
Michael Maguire, Tennessee Valley Authority

† ..... *
Jerome Dodson, Continental Savings & Loan, San Francisco

† ..... *
James Baressi, Northern Maine Regional Planning Commission

† ..... *
David Morris, Institute for Local Self Reliance

"Social Constraints on the Availability of Renewable Resources for Energy" 13-21
Dennis L. Meadows, Dartmouth College Resource Policy Center

† ..... *
Mare Older, Boston Redevelopment Authority

SESSION V: Thursday A.M.
Renewable Energy Planning for Small Regions

"Conservation and Renewable Energy Planning in Los Angeles" ..... *
Mark Braly, Office of the Mayor, City of Los Angeles

"Implementing a Local Energy Conservation and Development Plan: The Southern Tier Central Region's Energy Development Corporation" 13-23
Clara G. Miller, Consulting Planner, and *Steven Weisman,* Southern Tier Central Regional Planning and Development Board

"Renewable Energy Applications in New York City" ..... *
Margaret Morgan, New York Energy Task Force, Inc.

"Implementing Renewable Energy Through a Redevelopment Project" 13-25
Thomas Hirsch, Village of Soldiers Grove, and *William Becker,* Wisconsin Energy Extension Service

"A Local Strategy for Renewable Energy" 13-27
Ann Cline, Comprehensive Community Energy Management Program

SESSION VI: Thursday P.M.
Regional Renewable Energy Planning Exercise

"Renewable Energy Planning Exercise" 13-29
Dennis L. Meadows and Charles Hewett, Dartmouth College Resource Policy Center

SARDINIA ENERGY PLANNING

Andrea Ketoff
Lawrence Berkeley Laboratory
Berkeley, California, U.S.A.
School of Architecture, Polytechnic Institute of Turin (Italy)

A regional energy analysis for the Island of Sardinia (Italy) was carried out in 1978. It consisted mainly of the aquisition of a data base and processing of the data base with the same methodology applied by the study on Distributed Energy Systems for California's Future [1].

The Sardinia distributed energy system that was worked out strongly stressed the deployment of renewable resources, and specifically examined the important constraints that the Sardinian petrochemical and refining industry casts on such a strategy. Solar thermal and wind electric resources seem to have a great potential, due to the climate and to the rather distributed demographic pattern. Liquid fossil fuels for transportation were one of the hardest supply constraints to meet. This first study assumed current projections for demographic increments. GNP was projected to bring the average Sardinian income roughly at an 80% level compared to the national Italian average. The other general assumption was related to dephasing of the petrochemical industry which was going to be substituted -- in order to insure adequate employment -- by a "basket" of industrial activities with a reasonable mix consistent with the island environmental and human potential. The work was circulated, and stirred considerable interest both within the regional authorities and within the central government, since it was the first scenario relating energy and land use ever prepared for an Italian region.

In 1979, the data base and the general aquisitions were elaborated by a member of the research staff, Roberto Pagani, during a stay at the Brookhaven National Laboratory,supported by the Turin School of Architecture. The Reference Energy System for Sardinia derived from his work provides interesting information on two alternative paths, one based on centralized energy plants and the other based on decentralized resources. The comparison of the two systems does not supply clear cut information for decision making but it does indeed clear up some of the involved issues (see Sardegna 2010 [2] and Reference Energy System for Sardinia [3]).

The most important result of the two studies was to make various central authorities aware of the importance of integrated energy/land use planning. The studies clearly indicated that the only way to structure energy conservation strategies or any energy strategy with some insight of its actual implication on the wider related systems (environmental, social, industrial,transportation, agricultural) was to have consistent scenarios modeled on the various assumptions and hypothesis.

The interest in the two studies was such that both the CNEN (Comitato Nazionale per l'Energia Nucleare -- National Committee for Nuclear Energy) and the Sardinia Region decided to sponsor a third round on the project. The CNEN is going to supply the technical and scientific background; the local government of the Sardinia Region is going to supply political committment and sponsorship. The original working group staff will be integrated by research operatives of CNEN and by a liaison office staffed by the Region in Cagliari (capital city of Sardinia).

The main concern of the new round of study will be the updating of the data base, its detailed breakdown for the various activities and fields, and possibly its breakdown acording to time and space patterns so that time/space schedules for the various types of energy conversions may be drafted. The study will also supply more detailed information on specific activities and sectors (manufacturing, agriculture, petrochemical, alluminum, etc.).

The methodology shall substantially follow the standard path: 1. data base collection; 2. choice of models; 3. assumptions; 4. scenarios.

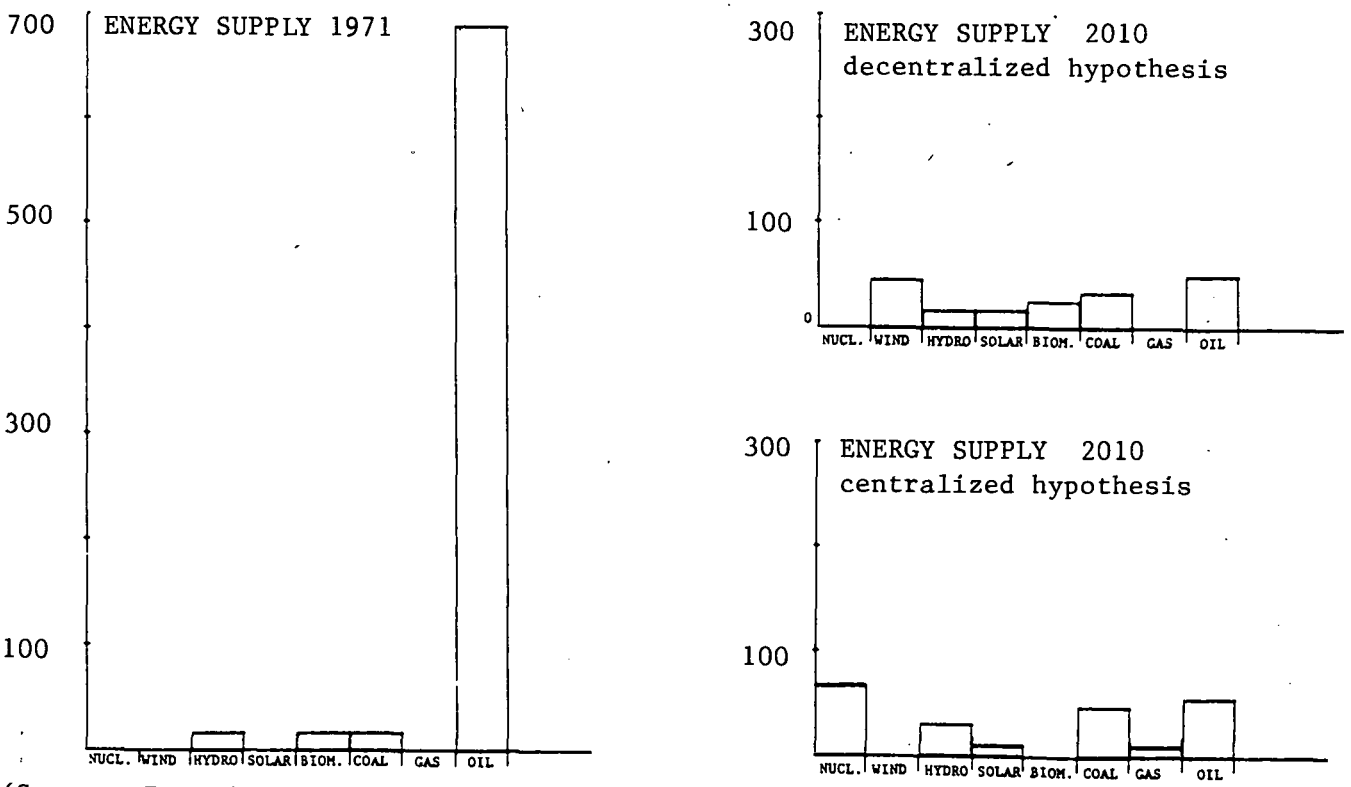
Data base collection. The data base shall be updated; careful consideration will be given at the possibility to have space/time/enthalpy breakdowns. Data shall also have to comply with constraints of the modeling tools.

Choice of models. The round will allow a comparison between some current modeli techniques in Europe -- derived from the CEE activities -- and in the USA.

Assumptions. The social and economic assumptions of the actual Sardinia Five Year Plan will be assumed with all their implications and constraints. More careful analysis on the technological assumptions will be made in order to consider the possibility to apply in Sardinia the solar pond technology associated with organic fluid electric generators and to give some responsibility to solar electric direct conversion (photovoltaic) by the end of the century. Lifestyles will be considered since the usual assumptions that lifestyles are not going to change seems unrealistic; the study on social implications will be assisted by a staff of antropolgists and social scientists of the Turin University. Careful attention shall also be given to the interactions between energy and economy either at micro- and at macroeconomical scale: the fact that Sardinia is an island does help in this problem area.

One of the main features of the third round on the Sardinia study is the close cooperation that shall be set up between the land use responsibilities of the Region and the energy culture: the primary goal of the program is the formation of institutions and professionals qualified and capable of carrying on the actual continuous work. The contract for the research is between CNEN and the Turin Polytechnics Institute and the work shall be directed and coordinated by prof. Lorenzo Matteoli who will also have its scientific responsibility.

1. Craig P., et al.(Lawrence Berkeley Laboratory/University of California), Distributed Energy Systems in California's Future. LBL 6831, 1978.
2. Matteoli L., et al. Sardegna 2010. Torino, Italy, 1979.
3. Pagani R., et al. Reference Energy System for Sardinia, Italy. Brookhaven National Laboratory, Upton, NY, USA, 1979.



(Source: Pagani et al, RES for Sardinia, BNL, 1979)

RENEWABLE ENERGY PLANNING FOR SOUTHERN USA, PUERTO RICO AND VIRGIN ISLANDS

Juan A. Bonnet, Jr., Director
Center for Energy and Environment Research
San Juan, Puerto Rico

Barry Graves, Director
Southern Solar Energy Center
Atlanta, Georgia

A comprehensive Plan of Energy Strategies for the Southern region with the goal of reaching 20% solar energy usage by the year 2000 has been prepared by SSEC.

Special attention has been given to the U.S. Caribbean Islands as part of the Southern region where oil use is the primary means of generating electric power. Comparisons are made with the States of Florida and Louisiana, the two largest users of oil for generation of electricity in the South. The 1979 oil consumption for Puerto Rico was 68.1 x 10^6bbl including approximately 26 x 10^6bbl for electricity production while Louisiana used 24.2 x 10^6bbl and Florida 86.2 x 10^6bbl for electricity production. Thus Puerto Rico consumption is a very significant portion of the total imported oil used in the Southern region. The annual out flow of dollars from the Puerto Rico economy might exceed 3 billion by 1985 or earlier. This is a dramatic and serious increase representing approximately 50% of Puerto Rico total government budget. This points to the need of a vigorous and strong program on energy alternatives usage for the region. The economic survival is at stake. The U.S. Virgin Islands are also faced with the same conditions. The potential of Biomass, OTEC, Photovoltaics and Wind and their economic competitiveness has been carefully evaluated by CEER (CEER-X-72 "Energy Analysis and Economic Considerations for Puerto Rico"- 1980). Mention is made of solar IPH, low grade heat applications, gasohol, etc. Estimates and scenarios are made and discussed with the key conclusion that early action is essential.

In the CEER study, dates or periods at which the renewable energy alternatives could be competitive with coal burning power plants were determined. (Coal is assumed to be an acceptable alternative because of availability and commercially available pollution control techniques). The projected period of competitiveness was then used to prepare a Research and Development Plan to make possible the earliest use of the renewable energy alternatives in the electrical generation expansion plan. Table 1 illustrates proposed scenario program objectives based on the mentioned analysis. Table 2 illustrates the estimated Puerto Rico fuel oil requirements for the period 1980-2000 with and without energy alternative development as discussed.

TABLE 1. SCHEDULE OF PROPOSED PUERTO RICO SCENARIOS PROGRAM OBJECTIVES ELECTRIC PLANT CAPACITY.

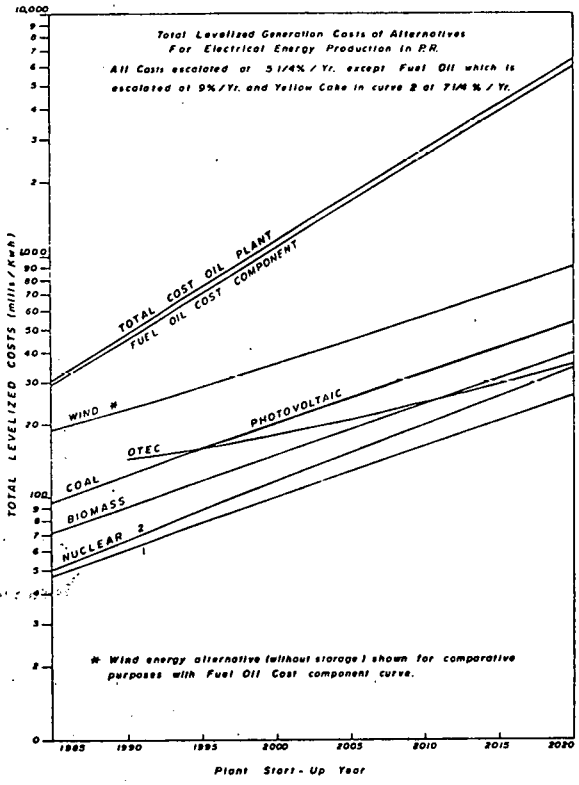
Year	Biomass	OTEC	Photovoltaic	Wind	Coal
1980-84	.....	.....	.....	200KW	.....
1985	.....	1-40MW	.....	.....	1-300MW
1986	1-300MW	.....	.....	.....	....
1987	1-300MW	.....	.....	.....	.....
1988	.....	.....	.....	12.5MW	.....
1989	.....	.....	.....	.....	1-400MW
1990	.....	.....	.....	.....	1-400MW
1991	.....	1-250MW	.....	.....	.....
1992	.....	1-250MW	.....	.....	.....
1993	.....	.....	1-250MW	.....	.....
1994	.....	1-250MW	.....	.....	.....
1995	.....	.....	1-250MW	.....	.....
[illegible]	.....	.....	.....	.....	.....
[illegible]	.....	.....	.....	.....	.....
1998	.....	1-500MW	.....	.....	.....
1999	.....	1-500MW	.....	.....	.....
2000	.....	.....	.....	.....	.....

TABLE 2. Summary requirements in 20 year period (1980-2000) for Puerto Rico under no renewable sources program and under renewable energy proposed program.

	Millions of Barrel of Oil				Estimated Cost
	Electrical Generation	Gasoline & Diesel	Industry & Others	Total	Total Cost Million of Dollars
No Renewable Sources Program	1033.0	491.0	941.0	2465.0	$155,829
Renewable Sources Program Savings	236.0	141.0	60.0	437.0	$ 27,612
Net Needs with Renewable Sources Program	798.0	350.0	881.0	[illegible]29.0	$128,217

In general the CEER study indicates that nuclear plants will be the least expensive source of energy (by a factor of 2 or more) for the rest of the century and beyond. Oil fueled base loaded power plants will be the most expensive alternative by a very large factor when compared either to coal or nuclear. Figure 1 illustrates plant start-up period vs. total levelized cost during plant lifetime in mills per kw-hr. As seen from Figure 1, OTEC and photovoltaic power plant costs are equal to the coal plant alternative just before 1995. Biomass is competitive with coal right now. Beyond the year 2000 the OTEC alternative can become competitive with coal and if technically successful can become a strong contender economically with the nuclear alternative.

FIGURE 1



The socio-economic impact for Puerto Rico of the first 2-300MW Biomass and first 250MW OTEC plant was assessed. This resulted in a tremendous improvement of the balance of of trade and job creation. The projected energy production from the alternative energy sources presented in the CEER plan comply with the "20% solar goal" announced by the President for the electrical generation scenario but falls short by 3% difference for the overall energy picture.

Recognition of the total impact on the Caribbean Island Community follows along the lines of an adequate assessment of indigenous alternative energy sources. A brief background of the Lesser Antilles, including history, cultural, and linguistic diversity is given along with a discussion of their dependence on imported petroleum and tremendous economic restraints. The hope for solving their energy problems rest on utilization of their common geographical and ecological situations. Extensive natural energy resources exist in the area in the form of solar radiation, ocean currents, wind and geothermal formations. These energies must be redirected to meet human needs. A discussion of on-going energy efforts in the region precedes a detailed account of new opportunities for technical cooperation.

The problem of the lack of adequate capital is discussed and recognized as one of the greatest constraints.

The general conclusion is drawn that prompt action in developing alternative energy sources is of primary importance.

ENVIRONMENTAL ASPECTS OF REGIONAL PLANNING FOR RENEWABLE ENERGY

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The last decade's increased attention to environmental characteristics of energy technologies is not a temporary aberration but the precursor of general recognition that environment is central to the energy dilemma, not peripheral. For the essence of the energy dilemma is not imminent depletion of fossil or nuclear fuels, nor even inability to pay the economic costs of mobilizing them; rather, it is how to steer a course between the economic costs of having too little energy and the environmental consequences of having too much. (I interpret environment broadly, to include not only biological and geophysical but also sociopolitical components.)

This emerging perspective on the nature of the energy problem is responsible for much of the interest in renewable energy sources, which are widely perceived as posing smaller environmental hazards than do conventional, nonrenewable sources. To some extent this perception is correct, but there are some caveats and complications of which regional planners dealing with renewable energy options should take note.

First, no energy option--not fusion, not conservation, not even the best of the renewables--is free of environmental liabilities to the point where these can be ignored in planning. One set of liabilities generic to many (but not all) renewables technologies arises from their land-use requirements, which by their nature sometimes burden fragile and/or highly prized environments. Destruction of free-flowing rivers and rare ecosystems for hydropower development, erection of windmills on scenic coastlines and mountain ridges, and deployment of sprawling solar-thermal-electric power plants in the deserts of the Southwest are examples. A second set of generic liabilities consists of the effects, on public and occupational health and on ecosystems, of extracting and processing the materials needed to construct the collection systems. Occupational exposures to and emissions of silicon, cadmium, and arsenic for photovoltaic cells fall in this category, as do the occupational and public hazards of mining, transporting, and fabricating the materials for such massive collection systems as heliostat arrays and windmill fields. A third set of liabilities consists of accidents (fires, falls, leaks) and nuisances (sights, sounds, smells) in routine operation and maintenance of renewable energy technologies. Dispersed rooftop collectors and urban windmills pose problems of this kind. A fourth set of problems involves alteration of microclimates due to large-scale intervention in natural energy flows. Large hydro projects have produced such effects in the past; large-scale wind development, OTEC, and biomass plantations may do it in the future. Biomass farming, in fact, also has a set of problems all its own: high consumptive water use where irrigation is required, offsite effects of fertilizer and pesticide use, indeed most of the well-known impacts of high-yield agriculture and forestry. Even the use of residues from existing food or timber cropping may cause problems (e.g., loss of soil quality), and conversion and combustion of biomass from whatever source are not free of emissions. (Wood stoves can be particularly nasty polluters.)

All this is not to suggest that renewables are worse environmentally than coal and oil and fission; mostly, I think, they will prove considerably better. But

they will not, in general, be significantly less demanding than conventional sources in their need for systematic and thorough attention to the minimization of environmental hazards via shrewd selection of technologies, integration of siting strategies with other community and regional goals, and implementation of management and monitoring schemes that ensure optimum performance.

Particularly to the extent that the use of decentralized technologies for harnessing renewable energy sources is contemplated, planners will find that involving the public in the planning process is even more crucial to success than has been the case with the more centralized, conventional technologies, simply because more people will find themselves directly affected. Herein lies both an asset and a difficulty. That is, it is a particularly pernicious characteristic of fossil fuels and nuclear fission that their environmental liabilities reach out, both in space and in time, far beyond the users and choosers of the technologies. (Think of: carbon dioxide, heavy metals, mutagens, and acid rain from fossil fuels; and weapons proliferation, nuclear terrorism, and long-lived radionuclides from fission.) This characteristic means that the environmental burdens of these technologies are being distributed far more broadly than are the economic benefits, a situation that is both unjust and inefficient (the latter because people who are not paying the full costs of their consumption will not make socially efficient decisions about how much energy to consume and how to supply it). The asset of decentralized renewables in this respect is that they tend to impose their main environmental burdens on the users of the energy or on those the users must compensate (e.g., the workers who build and maintain the systems), fostering both fairness and efficiency. The difficulty is that people do not like paying the full costs of their consumption if they can help it--this has been a major attraction of conventional centralized electricity generation, wherein part of the price of air conditioning New York and Los Angeles has been paid in Appalachia, Montana, and New Mexico. Getting one's "constituents" to live with the consequences of their own consumption may be the regional energy planner's toughest task in the emerging era of renewables.

THE HAWAII INTEGRATED ENERGY ASSESSMENT

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&

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Hawaii, which depends on imported petroleum for almost 95% of its energy needs, could become the first modern industrial region to navigate the transition to full reliance on renewable and geothermal energy. The abundant indigenous resources include intense sunshine, the trade winds, a rich biomass potential, ocean thermal energy and geothermal energy. Together they could eventually provide all of the State's future energy needs. The dilemma facing decision-makers is how best to carry out this transition, and determining the potential impacts. If Hawaii does achieve this transition, it will serve as a "pathfinder" for other regions and even nations in the development of integrated energy systems based increasingly on renewables.

The Hawaii Integrated Energy Assessment (HIEA) is a collaborative research project of the Dept. of Planning and Economic Development and the Lawrence Berkeley Laboratory. The project was established to help assess the feasibility and impacts of possible alternative energy paths for Hawaii over the coming quarter century. The analysis is aimed at providing decision-makers, including the public, with both information and procedures to aid in the development and implementation of a suitable long-range energy strategy. The project is supported by DOE's Office of Conservation and Solar Energy and Office of Resource Applications, and by the State. This work is part of a larger DOE-sponsored effort nationally to identify methods and information related to energy planning and the state and local levels.

The objectives of the HIEA include energy demand forecasting, technical, economic and environmental characterization of the relevent energy supply technologies, establishment of data bases on energy supply and end-use patterns and identification of important regulatory, institutional and social issues related to use of new energy technologies in the State. Other objectives include development of projections for the possible rate and scale of use of new energy technologies in Hawaii, development of energy demand/supply "mixes" which best match economic, technical and social goals, and evaluation of the economic, labor and materials requirements for alternative energy futures.

The project has developed a range of analytic tools and data to help achieve these objectives (1). A detailed evaluation of the range for energy demand over the coming 25 years was accomplished through use of the DPED/LBL Hawaii Energy Demand Forecasting Model (2). Results in Figures 1 and 2 indicate (with the unrealistic Case 4) the probable demand range. The role of energy conservation is quite dramatic even with modest assumptions for the extent of improved efficiency of energy use. Other work includes development an extensive energy data base and input/output tables for the counties for

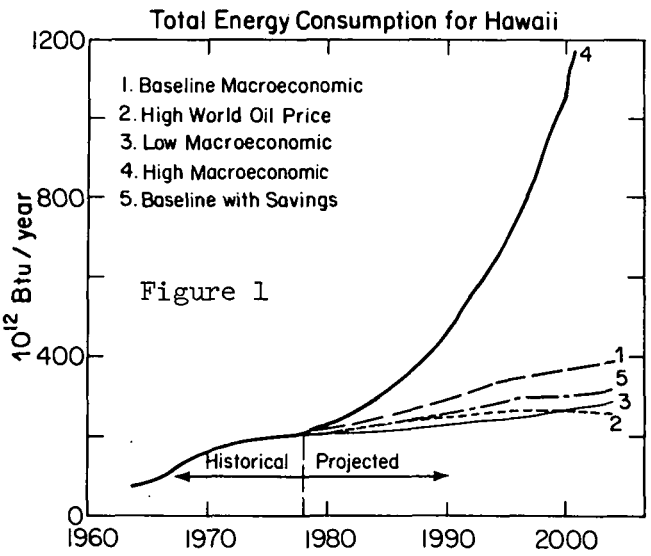


Figure 1

1977. An analysis of the economic impact of oil shortages in the State has been conducted, and procedures for integrating the various energy options into an economically sensible and technically functional combination have been developed. A set of such integrated supply/demand scenarios are under development (at press time) and will be presented at the Conference. Other work included the calculation of explicit economic and labor impacts of alternative energy paths. An assessment of social, institutional, regulatory and environmental issues was conducted and their significance as possible constraints and/or supports for use of indigenous energy systems evaluated. We also conducted preliminary investigations of the possible roles for coal-based fuels and for nuclear power as interim energy options for Hawaii.

Some preliminary conclusions are: (1) An aggressive, cost-effective energy conservation program permits suffient long-range energy savings to permit local biomass fuels to provide most or all automobile requirements; (2) the transition to indigenous energy resources will compete favorably with oil over the coming 3 decades, with some options attractive soon on a fuel-displacement basis alone (Fig. 3); (3) increased efficiency and higher oil prices will reduce otherwise projected demands for electricity (Fig. 2); (4) the replacement value of oil, in the event of severe oil shortages, will exceed present world price by a factor of two to ten, suggesting re-evaluation of the role of a strategic petroleum reserve in Hawaii; (5) energy independence for Hawaii will require inter-island biofuel shipments and probably inter-island electrical connection; (6) substantial regulatory, institutional and social issues must be resolved if renewables are to achieve their full potential; (7) the electric vehicle appears of little significance potentially, either in fuel displacement or energy savings in this century in Hawaii; (8) coal-based fuels may be an important interim option but nuclear energy will not be in this century, and probably never. These examples suggest some of the results of the study. Overall, the transition to renewables is possible, appears affordable though not cheap, and attainable in about three to four decades.

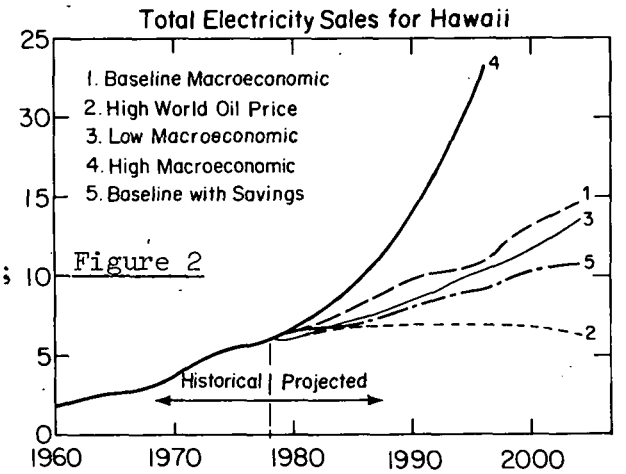
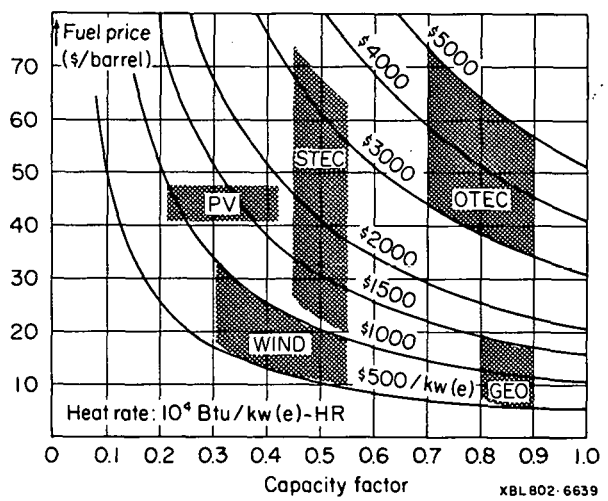


Figure 2

FUEL DISPLACEMENT BY
Fig. 3 RENEWABLE ELECTRICITY SYSTEMS



(1) For details, see the multi-volume report of the HIEA, available from DPED, LBL and DOE early in 1981. A mid-year (1980) progress report is available now.

(2) P. Leung and H. Ruderman (1980), "The Hawaii Energy Demand Forecasting Model" (available as part of the HIEA multi-volume report)

"APPROPRIATE BUREAUCRACY" FOR RENEWABLE ENERGY DEVELOPMENT: THE ROLE OF SUB-STATE REGIONS, COUNTIES AND UNITS OF LOGAL GOVERNMENT

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The Southern Tier Central Regional Planning and Development Board (STC) is a sub-state regional planning agency located in Corning, New York. It has been engaged in a variety of energy activities, including participation in the Department of Energy's Community Level Technology Assessment Program, since 1977. When STC started work on its regional energy plan, the idea that regional or local government agencies could or should have any role in planning for the use or development of renewable energy resources was novel and was not widely accepted. Since that time, a proliferation of energy initiatives at the sub-state level, the introduction of several pieces of federal legislation aimed at supporting local energy planning and development efforts, and increased executive recognition of the vital role of local governments in national energy programs have made it clear that the local role in energy activities is important. The wide acceptance of the local role in energy planning and development has led to a reassessment by all levels of government of their own roles in effectuating energy policies.

When planners and citizens began work on the STC regional energy plan in 1977, it was with the idea that the local role was of singular and perhaps of sole importance to renewable energy development. Participants worked on the plan under a hypothetical set of constraints which made them responsible for producing a plan through which the region could become energy self-sufficient to the greatest degree possible. The participants were given absolute, emergency powers within the region and were given these powers as part of a national energy emergency that formed the backdrop for their planning efforts. Thus, self-sufficiency and decentralization were guiding concepts in their efforts.

Although the participants found that they could make great progress toward their goals, especially when operating in the scenario which gave them complete power and few constraints in terms of technological supply, when they began to translate their "ideal" plan into a present-day "action" plan, they found it necessary to expand their field of actors to include those outside the region, and in many cases, the state. As part of this expansion, they began to assign roles to a variety of levels of government for renewable energy development on the basis of their legal powers, political efficacy, technical abilities and sensitivity to a given level of social impacts of technological change. The ascertainment of these roles--which might be called an exercise in "appropriate bureaucracy"--is an important part of any planning process. For renewable energy planning it is especially important, since it underscores the weaknesses as well as the strengths of existing political and social institutions in simultaneously initiating and regulating widespread use of renewable energy technologies.

Although citizens and planners taking part in the STC planning process spent most of their time on defining roles at the sub-state level, they were able to recommend appropriate activities for state and federal agencies as well. As their planning proceeded, the citizens redefined, by assigning "appropriate bureaucracies" for the accomplishment of energy goals, the familiar renewable energy planning concepts of

"decentralization" and "self-sufficiency." While the findings of the citizens characterized below does not result from systematic research aimed at thoroughly defining such roles throughout the governmental system, they are based on the observations made by the participants in a practical, normative planning process.

As is the case for environmental quality planning, renewable energy resources planning often requires action on resources by governments whose boundaries or powers are not compatible with the geographic distribution or patterns of use of the resource. The question of "appropriate bureaucracy" is therefore often decided, appropriately or not, by the existing pattern of government control.

The table below summarizes bureaucratic needs or actions available to various levels of government for planning and development for renewable resources.

ACTION		RESOURCE	ACTOR/ROLE
General	Sub-Category		
PLANNING	Data Gathering	Solar Wind Biomass Waste Water Conservation	• Local/Inventories of shading; Building Patterns; City & Regional/inventory well-oriented land, "dark" slopes. • Local/airport wind data; City & Regional/Inventory of prime wind sites; State/Federal: use of air quality monitoring stations for wind speed data. • Local/sewage treatment plant inventories; County/State/State Forest Inventory; Soil Surveys: animal counts (USDA Ext). • Local/Landfill location and content inventory; City & Regional/mapping of landfill sites, and organic waste producing industries. • Local/State inventory of old mill sites from historic maps; streams with volumes and flow characteristics; Federal: "208" Groundwater models; River Basin Comm's: same. • Local Utilities and States/aggregate consumption data on the basis of political subdivisions.
	Plan Formulation	All Resources	• Local/Emergency contingency planning; zoning/solar access; building codes; plan that matches use/technology and resources (local mapping). • County/Regional: Areawide renewable resource plans; hybrid systems; preliminary utility matchups; intermunicipal and intercounty projects. • State: State emergency contingency planning; large-scale renewable resource projects coordination of water-based projects and agricultural resource projects. • Federal: Emergency energy planning; Aid to local energy planning and development efforts through funding and regulatory reform; Broad development goals.
DEVELOPMENT	Resource Development	All Resources	• Local/City & Regional: Form local corporations or public authorities to initiate, direct and pool capital for local resource development projects (work with private entrepreneurs). • State: Float bonds to fund local and state renewable resource projects: distribute proceeds to local entities. • Federal: Project funding; Renewable and Cons. Development Banks; Preservation of resource flows to poor and otherwise disadvantaged through subsidy to local projects.
	Commercialization	All Resources	• Local, City & Regional: Encourage formation of consumer cooperatives for technological cost and risk sharing, e.g. solar buying and installation; shared storage, etc.; set up arrangements with utilities. • State: consumer protection; utility regulation to encourage utility investment in solar/renewable and conservation equipment. • Federal: testing; Bank policies, lending policies.

A companion table (not included here) that traces appropriate government levels for a variety of regulatory actions summarizes the participants' observations in such areas as emergency regulations, energy pricing, incentive and punitive taxes, land use and building regulation, banking policy and equipment standards. Among the areas participants thought needed most attention were the creation of local contingency regulations and procedures for energy emergencies; legislation on all levels for the preservation of renewable energy resources; and the reform of utility and bank investment policies to aid local, small-scale energy development.

IMPLEMENTATION OF RENEWABLE ENERGY TECHNOLOGIES IN THE FACE OF INSTITUTIONAL CONSTRAINTS

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There is a range of alternative and renewable energy technologies which can be used in different localities. Their feasibility is not purely an engineering and economic problem. Examples include photovoltaics, large scale wind power and biomass conversion. In each case there will be an array of institutional and legal impediments to their implementation. Some of the laws and policies operating in the United States include the Public Utility Regulatory Policy Act, the Energy Tax Act and the Power Plant and Industrial Fuel Use Act. Some of the impediments may have general societal support, while others may be remnants of older technologies.

Among the institutional constraints are tax policies, on the Federal, state and county levels, zoning and planning laws, utility rate regulations and direct environmental management laws. To illustrate tax problems which can occur, we can look at the example of implementation of a biomass boiler by a utility on Oahu. If the utility wishes to get the full advantage of Federal tax benefits for small power production facilities, it must purchase power from a biomass boiler in which it owns less than a 50 percent share. This Federal tax policy may be a valid societal judgement in order to promote competition, but it has to be integrated with the rate setting process. Similarly, a utility may have a declining block rate structure which will discourage a user of the utility's service from perhaps introducing their own wind turbine since the less electricity they use, the higher unit price they pay.

An example of a planning and zoning impediment would be the use of a photovoltaic array on a separate building in a residential neighborhood. The zoning and planning laws could come into play in two different ways. If a zoning law is of the kind which only allows permitted uses, such an array may be totally disallowed. On the other hand, the lack of zoning and planning control over solar access may inhibit persons from building such a solar array because of a fear that they will lose part or all of their sunlight. An environmental example would be the implementation of a small hydroelectric generator (less than 8 MW) which may interfere with fish populations, even though it may have a favored status under the public utilities regulatory policy.

There are many other institutional constraints which should be considered in designing renewable energy systems, either concentrated or decentralized. This paper will review the major regulatory and institutional issues affecting the large scale use of renewable energy technologies. Some specific examples of regulatory issues surrounding the use of wind energy and other renewables in Hawaii, on Block Island, RI and elsewhere will be discussed. One example will be the regulatory contraints in the form of wheeling and power pooling regulations by the Federal Energy Regulatory Commission in the event that power lines were to link, for example the islands of Molokai and Oahu. There is an array of Federal and state laws governing the sugar cane and pineapple industries. These laws may be at cross purposes either directly or due to their economic effects on energy production from renewables. In an isolated island environment with a single lens of fresh water under-

lying the island, the use of the coal option rather than an option which does not involve any form of waste may be more directly affected by water control and pollution laws.

The paper will conclude with a discussion of regulatory and policy initiatives which would enhance the potential role of renewable energy technologies in the United States in general and in Hawaii in particular.

KEY FACTORS AFFECTING REGIONAL PLANNING FOR RENEWABLE ENERGY TECHNOLOGIES

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Regional planning for renewable energy technologies has been investigated by the Department of Energy over the past three years, and this presentation is based upon the key findings from those studies. The studies were unique in the sense that they provided a "crosscut" across the technologies, using the same assumptions, whereas earlier studies had been conducted for only one technology (e.g., wind, photovoltaics, etc.). Key factors that affect regional planning were identified and are discussed below. These will be expanded upon in the full presentation.

RESOURCE

The magnitude and quality of the resource is a key factor. Early studies characterized the resource in terms of average annual values, but it is now apparent that a time series is necessary. The correlation between the resource and the loads to be met can significantly affect the value of the technology to the region. Insolation-based technologies have shown potential in the south central and southwest U.S. whereas their value is low for some of the northern states. Poor direct normal components have substantially reduced the regions in which solar thermal electric appears to be feasible. Wind shows great potential in regions when the resource is high and the wind-load correlation is good (e.g., California, Hawaii, and the Northeast). It is important for regional planners to consider the resource time series in conjunction with the electric load time series for their region. Biomass resources are substantial, but competition for the resource is keen and transportation costs are high.

SITING

Siting has emerged as a key issue. Wind resources in the Northeast are excellent along the coast, as they are for the Great Lakes, but the population density is also high. Wind resources are excellent in mountainous areas, but there has been some resistance to siting turbines in these regions. Dispersed wind systems often are considered for suburban areas with mature trees, thus requiring tower heights that violate local zoning (height restriction) codes. Large resource variability site-to-site, in the same region, places a heavy burden on planners trying to assess the potential for renewable technologies. Land area requirements for photovoltaics and solar thermal electric systems often are prohibitive due to site costs (e.g., Hawaii). Siting of solar systems must be done in regions where the resource is acceptable and land is available. This may result in central station sites being outside the service area of a utility.

UTILITY CONSIDERATIONS

One of the most critical factors in regional planning are utility characteristics. Utilities with oil-fired capacity show the best economics, often in spite of a moderate resource. Wind and photovoltaic systems will be economically viable in the Northeast before they will in the Plains states - even though the latter's

resource is stronger. PURPA will cause rate structures more favorable for solar technologies in oil-fired regions than in coal, nuclear, or hydro-dominant regions. Regions with good hydro resources (e.g., Pacific Northwest) offer the possibility of synergism with stochastic (solar) resources, but require that the technologies compete with low average cost electricity.

LEGAL/SOCIAL/INSTITUTIONAL ISSUES

The perception of how serious the energy crisis is, varies from region to region. Hawaii and the Northeast are more receptive (oil dependence) to new technology than some regions in the interior. Public Utility Commission activity varies, as does utilities interest in renewables. Serious zoning issues (e.g., height restriction, set-back distance, etc.) will retard market development in some regions. A preference for older homes (colonials in New England) may reduce the retrofit market. State utility legislation may restrict cogeneration and third-party owner, such as wind farms (Nebraska). Tax incentives can accelerate market emergence, but may be preempted in some states due to strict zoning requirements.

THE NEW ENGLAND SUSTAINABLE ENERGY PROJECT

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Before joining MITRE, I was Director of the Maine State Energy Office. In the fall of 1976 I was working on a Comprehensive Energy Plan for the state when a friend and advisor of mine, a retired official from the Central Intelligence Agency and a regular reader of Foreign Affairs, brought Lovin's just-published article to my attention, deeming it "an incredibly important piece of work." I believe that events have proven his judgment to be correct.

By February of 1978, then at MITRE, I reasoned that it would be useful to explore Lovin's concept of the "soft path" as applied to the New England region. Could it be done? That is, would it be plausible to consider a New England transition to an energy system based largely on renewable energy resources (coupled of course with highly efficient end uses)? I spoke about this concept with Dennis Meadows, Director of the Resource Policy Center at Dartmouth, who introduced me to Jim Quinn at DOE, and from our shared efforts NESEP was born.

First, I developed an analysis methodology for the project, designated Report #1 in the list of reports at the end of this abstract. Several researchers contributed their insights to this methodology, in part through a symposium held by Dartmouth and the Solar Energy Research Institute. (Report #2 contains the proceedings from this Symposium.) One important conclusion that we reached is that it is important in a regional study of this nature to perform "field tests" of the concepts, involving actual, case-study communities. Through such efforts we hope to learn much about the practical aspects of the transition to conservation and renewable energy systems: such aspects as financing, institutional barriers, resource availability, technological readiness, and the value that communities assign to energy self-sufficiency.

In the next phase of the project, sponsored by Bob Odland at the Solar Energy Research Institute, several studies were undertaken to prepare for the field tests and to gain more understanding of the renewable resource base that exists within New England and the technologies that might be deployed. Reports #3-5 cover these aspects of NESEP.

Currently, we are working with six case-study communities, (Ashland, ME, Belfast, ME; Boston, MA, Greenfield, MA; Hanover, NH: and Hartford, CT); selected to represent New England's diversity. Our goal is to develop, with the full participation of each community, a plan of action that will move the community as quickly as possible away from dependence on foreign oil and toward a sustainable energy future based to the maximum practical extent on conservation and renewable energy systems.

Not surprisingly, we have found that each community approaches its energy planning in a slightly different way, based on the different experiences and priorities of its citizens. However, there are some common threads emerging that should be noted by energy policy makers: (1) In each of these six communities, there are several leading local citizens whose understanding of energy issues and options is quite sophisticated and well informed. (2) There appear to be two approaches to energy self-sufficiency: the "comprehensive planning approach" and the "project implementation approach." (3) No matter which of the two approaches the community

seems to use initially, it seems to evolve toward the other fairly soon, so that both proceed simultaneously.

In future phases of the project, based on what we have learned at both the local and regional levels, we hope to be able to draw some conclusions about the plausibility of the transition for the New England region. Most importantly we hope to be able to define much more clearly how communities can, with minimal outside assistance, design their own transition.

Reports:

1. Page, A.: New England Sustainable Energy Project: A Feasibility Assessment, MTR #3685, The MITRE Corporation, Bedford, MA 01730, May 1979.

2. Regional Soft Energy Paths: A Transcript of the Dartmouth - SERI Symposium, Resource Policy Center, Dartmouth College, Hanover, NH, December 1978.

3. Mitsock, M.: Energy Technologies for New England, MTR #79W00435, The MITRE Corporation, Bedford, MA 01730, January 1980.

4. Glidden, W. T. and High, C. J.: The New England Energy Atlas, RP#260, Resource Policy Center, Dartmouth College, Hanover, NH, July 1980.

5. Spencer, S. and O'Brien, C.: New England County Energy Plan Data Book, DSD#193, Resource Policy Center, Dartmouth College, Hanover, NH, November 1979.

THE VALUE OF DISPERSED INTERMITTENT ELECTRICITY GENERATION

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This paper explores the economies that may be obtained through interconnection of large numbers of dispersed electricity generating systems. Dispersed electricity generation can be subdivided into two types: those which can provide firm power whenever needed, and those which provide power to the grid as a byproduct of some process that is beyond the electric utility's control. This analysis is concerned with the latter category, which includes most generators driven by intermittent (but partly predictable) renewable resources such as solar, wind, and small-scale hydro, as well as cogeneration systems that operate to meet (partially predictable) demands for low-to-medium temperature heat (or high temperature heat for bottoming cycles) in a variety of industrial, commercial and residential applications.

The value of dispersed power generation is the excess of its benefits over its costs. This paper will deal with only a few of the more easily quantifiable benefits and costs of dispersed generation: the cost of small-scale power generating equipment, and the benefits resulting from the utility's avoidance of central-station generating costs. Other important factors such as the costs the utility may incur or avoid in changing transmission, distribution and system control and dispatching systems are not treated here.

To the electric utility, the output of these intermittent dispersed generators is most easily viewed as reducing the demand its conventional generating units must meet; these intermittent generators are not generally available for economic dispatch by the utility. However, these "negative demands" are about as predictable as the other loads that make up the utility's total demand. Meteorological factors affecting the availability of renewable resources are to a great extent predictable on a seasonal and often daily basis, but not hour-by-hour. Moreover, the output of co-generators closely tracks the predictable operating hours of industrial and commercial establishments, and the seasonal pattern of space conditioning demands in buildings.

There are three ways in which such "intermittent" dispersed generators can be made to operate in such a way that their value to the utility grid is increased. The first and simplest is to make a firm commitment to schedule maintenance "down time" during a period when the power is least valuable to the utility. This option is open to all technologies under consideration, and is probably the only one available to large congenerators associated with industrial processes that operate continuously except for perhaps a few weeks of scheduled maintenance each year. The other two options are most appropriate for small power producers that operate only 30-70 percent of the time. One is to add enough storage capacity to allow operation in a mode that provides power to meet the utility's daily peak. (This would be most applicable to hot water storage at cogeneration sites, and perhaps short-term water storage at small hydro dams.) The third option is to add control equipment to the cogenerator, making it subject to economic dispatch by the utility during hours it would otherwise be idle. The cogenerator would simply waste its byproduct heat under such conditions, and would be viewed by the utility in the same way as one of its conventional peaking turbines (or one of its load-shedding devices). If the set of intermittent cogenerators is sufficiently diverse, there will be a nonzero

amount of idle capacity available at all times, dispatchable to meet some of the utility's reserve margin requirements.

Electric utilities exist to capture the economies inherent in the diversity of their customers' loads. These savings are of two types. First, capital charges are lower for grid-connected generators because they can be operated by much higher load factors than individual onsite generators, because of the negligible probability that all customers will reach their peak demands simultaneously. Capital savings also result from the fact that reserve margin requirements for the grid-connected generation can typically be kept as low as 15-20 percent, compared to essentially 100 percent for isolated onsite generators. This is due to the extremely high probability that many grid-connected generators will be available for dispatch at any one time. These benefits are common to all electric grids.

Dispersed power generation offers the opportunity for a utility grid, at a cost, to capture two additional types of benefits. In the case of cogeneration, operating costs are significantly reduced by the value of the fuel saved through waste heat utilization. The second type of benefit results from the connection of a diverse set of small power generators to the grid. This "supply diversity" is exactly analogous to utility's "demand diversity" in the sense that output from intermittent dispersed generation is seen by the utility as "negative demand." Since the utility has some control over the connection of dispersed generators to the grid, it could act to capture these benefits of supply diversity by connecting an "optimal" subset of dispersed generators. Several types of diversity are examined: 1) diversity <u>among</u> resources (e.g., solar, wind, hydro, cogeneration in various processes and building types), 2) diversity <u>within</u> resources (e.g., geographic variation in wind and sun, minor differences in cogenerator operating hours), 3) variation in design (e.g., wind cut-in speed, orientation of PV's, cogenerator electric/thermal ratio), and 4) variation in maximum capacity (e.g., wind cut-out speed, undersizing of cogenerators).

The final source of diversity, combining these dispersed power sources in an optimal fashion, is analyzed using a modified utility capacity planning model to determine the least-cost mix of conventional and dispersed generators. Solar and wind are treated as "negative demand," thermal storage associated with cogenerators is treated as a "negative battery," and intermittent cogenerators are treated in the model as generating during periods of "negative scheduled down-time," where the time periods are defined by the onsite thermal storage capacity and the amount generated is determined by the thermal loads during that period.

LOW ENERCY FUTURES FOR THE UNITED STATES

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A number of recent analyses have suggested that future consumption of primary fuels in the United States can be maintained at or below current levels, even though GNP and population continue to increase. The technical feasibility of this outcome rests not on any single breakthrough, but rather on numerous and diverse opportunities for improving the efficiency of energy use in buildings, appliances, transportation, and industrial processes. The term "efficiency improvement" means obtaining the same or higher output of energy related goods and services with lower energy input. The economic and political feasibility of these efficiency improvements rest upon a number of assumptions about future public policies. Such an outcome would depend upon public policies that account more fully for externalities such as environmental protection and national security, and upon public policies that help to correct market imperfections and biases.

These recent analyses of low energy futures are difficult to compare because of differences in basic assumptions, methods of analysis, time frames, and definitions of economic sectors. To assess their importance, we have selected ten representative studies and have attempted to reconcile their estimates to a common analytic framework and time period. We then extracted the main findings and recommendations in three major end-use sectors:

1. Buildings

   - thermal and electrical control systems
   - structural changes
   - appliance and space conditioning efficiencies

2. Industry
   - waste heat recuperation
   - cogeneration of heat and electricity
   - materials recycling

3. Transportation
   - automobiles, light trucks, and vans
   - other passenger modes
   - freight transportation

These studies have several major features in common. First, these studies are set in the context of continued growth in GNP, population, and the demand for energy-consuming goods and services. Second, they provide estimates of efficiency improvement measures that, when coupled with appropriate public policies, could result in negative growth in the demand for primary fuels. Third, these studies rely primarily upon technologies that are currently available, although not necessarily on a widespread basis. Finally, they assume no fundamental changes in "life-style" or standard of living as it is conventionally measured.

All the studies reviewed tend to concur on the technical and economic feasi-

bility of large reductions in primary fuel use through efficiency improvements. More specifically, these studies tend to agree that appropriate public policy measures could be taken to improve the efficiency of energy use. Such measures could be technically and economically consistent with continued growth in population and GNP, and could be lower in cost to both individual energy users and to the nation as a whole than expansion of conventional energy supply systems.

Major reductions in primary fuel use would affect a number of Department of Energy programs and policies. For example, the President has declared a national goal of supplying 20% of our nation's energy supply with solar by the turn of the century. The ease or difficulty of achieving this goal is directly related to overall total consumption levels, which our review shows might feasibly be in the range of 60 to 80 quads by the year 2000. If this is so, the size, nature, and timing of the markets for solar equipment might be markedly different than those projected in the Domestic Policy Review of Solar Energy.

These studies do not agree, however, in two important areas: The relative contribution of renewable resources in the future, and the relative importance of electricity (particularly with respect to electric vehicles). These issues are of significant interest to the design of future DOE programs and policies.

If suggested efficiency improvement measures could be widely and rapidly adopted across all sectors of the economy, the combined and cumulative effects are estimated by most of the studies reviewed to result in negative future growth in U.S. primary energy use -- possibly approaching 60 quads by the year 2000. The feasibility of such an outcome is dependent on a number of new or enhanced public policies at the Federal, State, and local level.

The objective of this paper is to review and evaluate some of the most recent policy suggestions to achieve such efficiency improvements in the U.S. economy. However, one should not expect a definitive set of policy recommendations to emerge from this initial review. More detailed analysis is needed to assess which of the many policies suggested are likely to be most fruitful. And, greater consensus is needed on the relative national importance of efficiency improvements compared to conventional energy supply expansion.

SOCIAL CONSTRAINTS ON THE AVAILABILITY OF RENEWABLE RESOURCES FOR ENERGY

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In determining the availability of renewable resources for energy, it has been easy to overlook the nonconsumptive uses that are in competition with energy. Many land owners derive psychic rewards from the possession of land that are inconsistent with rational, economic management practices. Many people in the vicinity of streams with potential hydropower sites have already grown accustomed to use of the water for recreation, for fishing, for maintenance of minimum water quality standards at sewage outfalls or for municipal consumption. They will naturally challenge efforts to divert the stream to power production, even when the dam owner owns the necessary water rights. Those in the vicinity of wind power sites may object to construction proposals on the grounds that a windmill is unsightly or would interfere with television reception. It is important to develop new techniques of measurement and improved data bases that will permit regional energy analysts to: 1) eliminate from consideration those resources that will not be available for use in production of energy, and 2) structure social or economic incentives necessary to offset social, institutional, and psychological constraints on the availability of the remainder.

During the past two years the Resource Policy Center has initiated an extensive set of studies to understand the relationship between those wood and hydropower resources that are physically available and those that are socially or institutionally available for energy production. Our study of wood resources focused on the nine northern counties of Vermont. From Forest Service statistics, data on twelve experimental whole tree harvesting projects, and land cover inventories we determined that the physical resources of this area would permit annual removal of 252 million cubic feet of wood fiber, beyond that already being harvested. This assumes liquidation of the rough and rotten standing crop over 20 years and implies that whole tree harvesting will not erode the fertility of the forested ecosystem. But 27 percent of the resource is inaccessible to mechanized harvesting systems because of steep slopes. Over 45 percent of the land area is more than one-half mile from any road - the maximum skidding distance. Of course there is substantial overlap between the lands unavailable because of slopes and because of distance. The attitudes of land owners are extremely important in governing supply of the resource. We polled public, corporate, and private woodland owners (265 individuals) to determine the circumstances under which they would permit whole tree harvesting and chipping on their land. Our best estimate is that about 50 million cubic feet would be available to a new wood-burning power plant in northern Vermont - clearly there is a great difference between physical and social resource availability!

At Dartmouth we have implemented a data base on the nearly 11,000 small-scale hydropower sites in the six New England sites. Of these dams about 1750 have physical characteristics that offer interesting amounts of power. If fully developed, these sites would provide about 1000 Mw of capacity at a capacity factor of about [redacted] to 50 percent. When current economic conditions are considered, the resource shrinks to about 80 sites offering potential annual output of 600,000 megawatt hours, one-sixth that available potentially from the 1,750 dams. If the effective interest

rate fell to 3 percent and dam operators were assured of sales at 67 mills per kilowatt hour, 581 of the sites become potential sources of power.

To guage the impact of social factors on actual resource availability, we took a sample of 37 sites from the six states and gathered information on ten dimensions of the dams' current status: fish passage requirements, wildlife habitat, recreational use, scenic value, historical value, reservoir shore use, water quality, local interests, water use by municipality, and dam's utility in flood control. Data on these attributes were presented to a diverse group of hydropower development experts and the sites were divided into three categories according to the potential conflict that a hydropower developer would encounter at the site. Because conflict can delay the licensing process, expose the project to substantial inflation, raise legal fees, strain the managerial resources of the developer, increase interest rates on debt, force the addition of costly additions to the capital requirements of the dam (for fish ladders or recreation), and enforce operating policies that reduce the amount of peaking power available from the facility, we decided that those dams in the "high conflict" category are effectively not a hydropower resource at present. In our sample of 37 dams, almost half the total capacity lies in dams of this class.

Of course social, institutional, and psychological constraints on renewable resource use can be altered by shifting social values, by changes in economic incentives, and by regulatory shifts. But for the moment our data suggest that wood and hydropower resources are severely limited by these factors. Regional energy planners must keep these constraints in mind if they are not to overestimate the resources available for the transition from oil to renewables.

IMPLEMENTING A LOCAL ENERGY CONSERVATION AND DEVELOPMENT PLAN: THE SOUTHERN TIER CENTRAL REGION'S ENERGY DEVELOPMENT CORPORATION

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The Southern Tier Central Regional Planning and Development Board is establishing a not-for-profit Regional Energy Development Corporation (REDEC) to finance local energy projects and to stimulate the development and use of renewable energy resources in Chemung, Schuyler and Steuben Counties of New York State. The Corporation will also encourage innovative forms of energy conservation, although its primary purpose will be local energy development. The REDEC will pool capital and expertise to directly aid the establishment of a local renewable energy technology and resource supply industry and to help initiate and expand efficient community use of such resources.

The Southern Tier Central Region of New York State faces energy related problems which are similar to those affecting communities, industries and individuals throughout the Northeast. These problems include an increase in money "exported" from localities in the region to pay for energy; rising energy costs and uncertain supply; and inefficient energy use. Local citizens, industry and union leaders and government officials in the STC Region are particularly concerned with the impact energy costs and supply fluctuations will have on local industry and employment. They believe that dependable, locally produced energy supplies and improved energy use efficiency are critical to keeping the region's industry healthy.

Last year, citizens, public officials and planners in the Southern Tier Central Region produced an Energy Conservation and Development Plan, which sketched the possibilities for the local development of renewable energy resources and conservation in the region. In this document, the planning group identified the lack of capital for energy projects as a major stumbling block to the use of new energy technologies and resources. The REDEC is designed to help fill this need.

The Regional Energy Development Corporation will use various financial and technical assistance mechanisms--a revolving loan fund, forms of equity investment, grants, loan guarantees and community-wide referrals--to assist both commercial and industrial entrepreneurs and energy consumers in all sectors in using renewable forms of energy. The REDEC will be regional and will be directed by representatives of such interest groups as government, industry, labor, utilities, energy conservation, elderly, poor, environmental and financial. REDEC will seek joint ventures with existing local development corporations, housing councils, community development corporations, industrial development agencies, utilities and others. It will also seek partnership with such extra-regional bodies as the Power Authority of the State of New York, the New York State Energy Research and Development Authority, and regional commercial and industrial establishments such as banks

and private utilities. Through this approach, the Southern Tier Central Regional Planning and Development Board hopes to provide a decisive push to the implementation of local community energy development policies and to new economic development efforts as well.

IMPLEMENTING RENEWABLE ENERGY THROUGH A REDEVELOPMENT PROJECT

Thomas Hirsch, Village of Soldiers Grove
William Becker, Wisconsin Energy Extension Service

A rural Wisconsin village is demonstrating to the rest of the nation that consideration of energy efficiency and renewable energy systems should be a normal, integral part of community development planning.

The Village of Soldiers Grove, located on the banks of the temperamental Kickapoo River, has been hit by nine major floods this century. In 1975, the community's 500 residents rejected an Army Corps of Engineers proposal for a $3.5 million set of levees, suggesting instead that the floodplain be evacuated and its buildings rebuilt on higher ground. The village's entire central business district, including 36 commercial structures, 3 municipal buildings and 22 homes, was to be involved in the move. Long accustomed to dealing with floods by building dams and levees, federal officials were slow to offer financial assistance for the project until the summer of 1978, when the Kickapoo devastated the village with the worst flood in its history.

As the move began in early 1979, villagers were concerned that their new downtown development be as energy efficient and environmentally benign as possible. Because of a disproportionate share of low income families and elderly people, villagers were also concerned about insulating themselves from rising fossil fuel prices and potential shortages. With the assistance of technicians from Argonne National Laboratory, the University of Wisconsin, University of Wisconsin-Extension, the Wisconsin Division of State Energy and the Hawkweed Group Ltd., a Midwestern architectural firm highly skilled in solar design, the village set out to "normalize" renewable energy planning in a community revitalization program catalyzed by the floodplain relocation.

Villagers decided to declare the new downtown site (a parcel of farmland about one-half mile from the old business district) a Planned Unit Development (PUD) district. Villagers then worked with Hawkweed and the University of Wisconsin to design a master plan for the downtown, including architectural standards and building placement. Under the PUD program, once the master plan was adopted by a newly formed citizen's planning commission, the plan would have the force of law. Approved in October, 1979, the master plan required:

*That all new buildings at the site achieve thermal efficiency of 4 BTU/sq.ft./DD, several times that required by state building codes;
*That all the commercial structures receive at least 50 percent of their heating energy from the sun;
*That the municipality retain ownership of all the land at the new site with the exception of the "footprints" of the new buildings, thus assuring solar access and solar-oriented landscaping. (In May, 1980, the solar access provisions were extended to all zoning districts in the village and the thermal efficiencies to all non-residential new construction.)

Villagers laid out the positioning of buildings at the site, taking into account the best siting for logistics, insolation and the best use of the microclimate (seasonal wind and temperature patterns, native vegetation and topography) to minimize energy use. Because the site is partially shaded during winter months by large

hills to the south, the master plan clustered the commercial structures to the north and utilized the shaded areas for parking. Finally, wood was chosen as a primary building material because it is a renewable resource abundant in the area, requires relatively little energy in manufacturing, and is a technology local builders can participate in. Hawkweed, working with most of the businessmen planning new construction, has developed a basic passive solar building design utilizing a "solar attic." Roof panels made of two layers of fiberglass reinforced polyester allow solar heat to be captured in insulated attic spaces. Thermostatically controlled fans move hot air through duct work into occupied areas. The architectural firm estimated that the solar attics, combined with good building design and high thermal efficiency, could typically produce 75 percent of each structure's space heating energy at conventional construction costs.

By the summer of 1980, five solar structures were completed at the new site and three were in full use. Utilizing the basic solar attic concept, good window placement, high insulation (typically R-36 in walls and R-72 in attics) and earth berming, each building was individually tailored for its particular needs. The village's new solar supermarket is designed to utilize waste heat from refrigeration motors, lighting and people as significant supplemental sources of heating energy. A major source of thermal mass for heat storage within the building will be canned goods on the shelves. Another building features a 20' x 8' trombe wall, triple glazed windows comprising more that 37 percent of its south wall, and site-built interior insulated shutters.

The project is expected to be completed by 1984. Because the passive solar design of the buildings was included as a normal part of planning and construction, utilizing conventional materials, the costs of solarization are being borne by businessmen as a normal part of their investments. No special grants or subsidies have yet been used in Soldiers Grove to encourage energy conservation and solar utilization.

Soldiers Grove intends to continue exploring other sources of renewable energy. The new commercial buildings are being equipped with conventional LP gas furnaces to back up their solar systems. The village plans to study the feasibility of biomass conversion, possibly from abundant wood wastes in the region, to fire the furnaces in the future. Although the project is small (the total development is expected to involve approximately 130,000 square feet), it is considered significant for several reasons. First, the development is one of the first in the nation in which stringent conservation combined with renewable energy systems use is required. Second, the project has been undertaken in a conservative, rural, northern community, indicating that solar heating technology can enjoy high social acceptability. Third, the village is demonstrating that as a normal part of planning, design and construction, passive solar heating is already an economical alternative to fossil fuels. Finally, the village is showing that grassroots people can find and implement creative solutions to their problems, that they can fashion a more stable future on their own initiative.

A proposal has been made to the State Energy Division to monitor performance of the passive solar systems in operation this winter to determine whether adjustments to the basic design are necessary for future buildings. Among the problems already experienced have been confrontation with state commercial building codes which were not designed to accomodate solar systems. For example, the state has classified the solar attics as heating ducts, and the attic construction of unprotected wood and fiberglass was not allowed. The village worked out an alternate building plan with state officials involving the use of fire protection measures.

Further technical information is available from Tom Hirsch, Community Development Office, or Hawkweed Group Ltd., Box 152; Soldiers Grove, Wisconsin 54655.

A LOCAL STRATEGY FOR RENEWABLE ENERGY

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As one of DOE's 16 pilot cities in the Comprehensive Community Energy Management Program, Richmond originally organized its two-year planning activities around a straightforward conservation format. However, during the process of a required energy supply audit, we expanded our account of traditional fuels to include an estimate of energy supply from renewable resources. What evolved from that step has become a major co-direction of Richmond's CCEMP effort. We began as a conservation directed program, and, a year later our Common Council passed an overall city energy strategy which emphasizes equally local energy development. In our case, local development includes some consideration of clean coal use as well as waste heat recovery from a municipal power plant. However, the larger number of projects we have proposed address the development of renewable energy resources.

Our first task in this endeavour was a systematic identification, and in some cases, quantification of our renewable resource supply. Our method of identification followed the work done in the Corning, New York study: Within the city's planning fringe, we have mapped prime locations for solar access, wind and groundwater resources. We have identified and mapped county woodlots and quantified regional garbage and other biomass resources as well.

The next step was to increase public awareness of these resources. Our overall dissemination strategy has been to "spoon feed" our final report in monthly bits which we believe have a chance of being widely read. We have, then, been publishing our "final" report in the format of a monthly newsletter for the past 15 months. The newsletter circulation is 1500 community leaders and interested citizens, and readership has been very high. Our newsletter energy supply series began with summary reports of traditional fuel supply; we simply continued the same format for renewable resource supply, quantifying and estimating present and future community consumption and reproducing prime location maps.

As a result of our renewable resource supply audit, we initiated two land use studies. One suggested ways in which a local developer might maximize the use of renewables on the site he has chosen to be his next community subdivision. This study paralleled the Shenandoah, Georgia method. The second proposal was more innovative. After initial studies suggested feasibility, we proposed using central city land bordering alleyways for future residential development. In Richmond these sites are often without original barn or garage buildings, and in some blocks are relatively attractive. In all cases roads and services are already in place and strict solar orientation is guaranteed by original grid system platting. A HUD grant helped subsidize the cost of building a prototype Alleyland solar house which is presently being marketed.

After identifying a course for renewables and after identifying community organization as key to this development, CCEMP organized two community groups--one for energy related professionals (architects, HVAC people, plant managers, etc.) called Energy Development Technical Assistance Program--and one for citizens, the Solar Interest Group. Each holds a series of yearly programs and meetings geared to the needs of the respective memberships for information or assistance. Among

the projects these groups have helped to formulate are a plan to retrofit several community buildings with trombe walls, a plan for retrofitting several typical Richmond residences and an offer to assist the Community Development Department and community lending institutions in a loan program, which would, among other items, offer interest rate subsidies for resident and community renewable energy technology projects.

In summary, Richmond's strategy for renewable energy resource development may differ from other community methods, -- particularly 'growth management' communities where regulatory measures are both effective and appropriate. Because we are a very slow growing community, regulations affecting new construction or real estate at point of sale can have little impact on our overall community energy future. As a consequence, the Richmond strategy emphasizes assistance and information programs for developers, professionals and citizens. Simply put, we are attempting to make easy a course of action for the community which we are unable to mandate.

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RENEWABLE ENERGY PLANNING EXERCISE

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In contrast to most large-scale conventional power sources, such as nuclear plants or coal strip mines, solar sources impose most of their costs on those who benefit from the power they produce. Nevertheless there remain important tradeoffs among competing users, between the short-term and the long-term resource availability, and within different localities of the region that is exploiting a renewable resource. For example, woody biomass energy poses many questions. In contrast to the annual increment, the standing stock of wood is a finite resource. Should it be exploited quickly or slowly? Should forests be used for recreation, for residential space, for preservation of wilderness, for production of wildlife, for agriculture, for collection of water, or for production of wood fiber? If the latter is the case, should the fiber be used in manufacturing wood products or for production of energy? If energy is desired, should it be from direct combustion or from conversion of wood to gas and liquid fuels?

Important constituencies can be found to promote each of these alternatives. Conflicts among competing demands on the renewable resource base are today resolved primarily through the market, despite signs, as in the case of farm land, that it functions poorly to produce equity or to maintain the resource base at high quality over the long term. Better planning and decision procedures are required by regional energy planners who wish to ensure that renewable resources are managed to produce a diverse array of social benefits at levels that can be sustained over the long term This is not necessarily a call for new planning bureaucracies. It may merely mean that we need better mechanisms to acquaint different constituencies with the extent of their common interest in compromise and consensus. This session of the Honolulu conference will afford its participants with brief exposure to a game developed to achieve this aim.

The staff of the Dartmouth College Resource Policy Center have worked with a community energy planning game, developed at the University of Michigan by Dresner and Thomas, to adapt it for use by those interested in the special dynamics of renewable resource harvesting and regeneration. Participants will be divided into teams with resource constraints and energy needs. Several iterations of the game will produce some useful insights into the cumulative impact of democratic decision making on a finite, but renewable resource base.

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