Proceedings from the

Energy Awareness Luncheon

and the

Energy Seminar

Presented by the
National Society of Professional Engineers
and the
Michigan Society of Professional Engineers

NSPE 46th Annual Meeting

July 23, 1980
Detroit, Michigan

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Price: Printed Copy A08
Microfiche A01

(Vol. 1)

CONF-800780-(Vol. 1)
Distribution Category UC-38

Proceedings from the
*Second Annual**

Energy Awareness Luncheon and Energy Seminar

Presented by the

National Society of Professional Engineers

and

Michigan Society of Professional Engineers

at the NSPE 46th Annual Meeting

July 23, 1980
Detroit, Michigan

Issued by the National Society of Professional Engineers

William A. Cox, Jr., P.E., NSPE President
H. E. Bovay, Jr., P.E., Chairman, NSPE Energy Committee

November 1980

**The first NSPE Energy Seminar was held during the NSPE's 45th Annual Meeting, July 11, 1979 in Knoxville, Tennessee.*

Renaissance Center Detroit, Michigan

Detroit's incredible renaissance has attracted the attention of the Nation and the world. In just a few short years, the cooperative efforts of business, labor and government has changed the vista of the city from one of a wasteland into a place of vibrance, life and the marketplace of commerce, industry and the arts.

Professional engineers have played a major role in helping Detroit move forward, and we will continue to look to NSPE members for leadership and excellence as we expand our efforts to rebuild Detroit.

Richard Simmons, Jr.
Deputy Mayor
City of Detroit, Michigan

Christopher P. Kittides, P.E.

Host Chairman

1980 NSPE Annual Meeting
July 20—26, 1980

Christopher P. Kittides, an associate with Smith, Hinchman and Grylls Associates, Inc., is the firm's assistant director of marketing. Prior to his work in marketing, he served as a project manager and project executive. A Ph.D. candidate at the University of Michigan, Mr. Kittides holds B.S. and M.S. degrees in civil engineering from the University of Southern California. In addition to the Michigan Society of Professional Engineers and the National Society of Professional Engineers, he is a member of the American Society of Civil Engineers, the Engineering Society of Detroit, the Michigan Association of the Professions, the American Water Works Association, and the Water Pollution Control Federation. In 1974 he was named Young Engineer of the Year by the Michigan Society of Professional Engineers.

The 1980 NSPE annual meeting in Detroit, Michigan, was a tremendous success. The total attendance was 1475, by far an NSPE attendance record. Helping to achieve this record were ten timely seminars and an exhibit program. One of the most significant events of the annual meeting was the Energy Awareness Luncheon and Energy Seminar, which was attended by 350 members and guests. Included among the guests were Detroit's deputy mayor, the president of the Detroit City Council, and a cross section of community leaders.

Christopher P. Kittides, P.E.

Lawrence W. Von Tersch, P.E.

MSPE President

L. W. Von Tersch is dean of the Michigan State University College of Engineering, a post he has held since 1968. Previously he chaired MSU's Department of Electrical Engineering and directed the computer laboratory. He came to MSU in 1956 from the faculty of Iowa State University, where he had earned his B.S., M.S., and Ph.D. degrees. A registered professional engineer, Dr. Von Tersch is active in the National Society of Professional Engineers and the Michigan Society of Professional Engineers. Other societies of which he is a member include the National Electronics Conference, of which he was president in 1960 and chairman of the board in 1962; the Institute of Electrical and Electronics Engineers, on whose Education Committee he served in 1964 and 1965; the Association of Computing Machinery; and the American Society for Engineering Education, on whose Engineering College Board he served from 1975 through 1977.


NATIONAL SOCIETY

Comments by Invited Guests

May I express my thanks to you for the kind invitation extended to me to attend the "Energy Seminar" in July of this year. While I was unable, due to the press of time, to attend any of the formal program, it was my extreme pleasure to be present at the luncheon on July 20, 1980, at which Mr. Kenneth Randall was the luncheon speaker.

All I can say is that Mr. Randall's presentation was superb, both in content and delivery, and if the quality of his speech was typical of the balance of the program, and I assume it was, the Seminar was indeed a worthwhile project.

Ivan Barris, President
Michigan Bar Association

My good friend, ex-banker Kenneth Randall, in his speech at the Energy Seminar, said in essence that we must turn the light of understanding on nuclear technology so we can create the energy necessary to fulfill America's destiny and enlarge the economic pie so that everyone will have a chance at a bigger piece.

Rodkey Craighead, Chairman
Detroit Bank & Trust

I was very impressed with Mr. Randall's address at the NSPE Energy Luncheon, and I stayed for the first part of the Seminar which followed. I thought Mr. Randall's remarks were very timely, to the point, and should help all of us understand the importance of energy conservation and the future use of energy.

I had an opportunity to talk to a non-Engineer, CPA, who was at the Luncheon and he was most impressed by Mr. Randall's address. I took this as a compliment on your program, coming from a non-Engineer.

Maurice N. Day, Vice President
Michigan Consolidated Gas Company








Comments by Invited Guests

The Energy Luncheon and Seminar, held July 23, 1980, in conjunction with the NSPE Annual Meeting in Detroit, was an outstanding and timely event. Kenneth Randall's keynote address set the stage for an in-depth panel discussion of the various sources of energy including oil, gas, nuclear and solar. The Energy Luncheon and Seminar was truly outstanding and made an impact with the Detroit civic and business community.

Peter C. Darin Jr., P.E.
Executive Vice President
Smith, Hinchman, & Grylls Associates, Inc.

I commend the National Society of Professional Engineers for devoting its expertise to the task of helping we laymen better understand the issues and options relating to our national energy problem. The luncheon and seminar discussions on July 23rd were provocative and informative, and a bit frightening. I'm sure the experience has propelled many of your guests into action.

Frank E. Smith, President
Greater Detroit Chamber of Commerce

I was impressed with the quality of the invitees and the leadership that they represented. The luncheon facilities were excellent and the keynote speaker, Kenneth A. Randall, was a very stimulating and obviously knowledgeable person in his field. I was unable to stay for the Seminar because of a previous commitment, but I did linger for a few minutes and I am sure it was also first rate.

John W. Harms, Vice President
The Detroit News

In order to promote energy awareness, the Energy Committee of the National Society of Professional Engineers is issuing these proceedings of the Energy Awareness Luncheon and Energy Seminar, held at the NSPE annual meeting in Detroit, Michigan, July 1980.

The Michigan Society of Professional Engineers was the host committee for the NSPE annual meeting.

H. E. Bovay, Jr., P.E.
Chairman of the NSPE
Energy Committee, 1979-1980
NSPE Past President
Chairman of the Board
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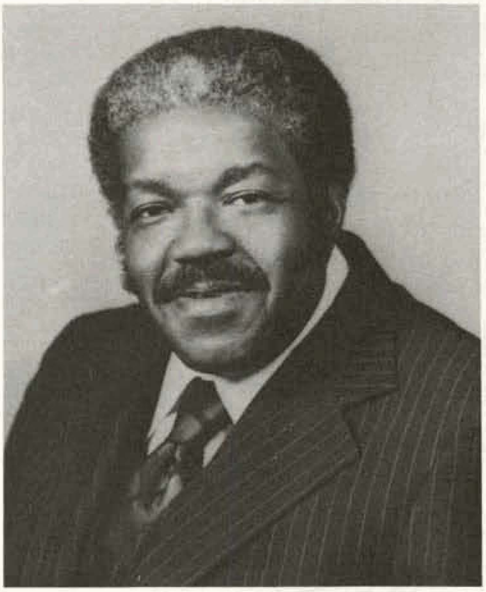

Welcome

Honorable Richard Simmons, Jr.
Deputy Mayor
Detroit, Michigan

Richard Simmons, Jr., is deputy mayor and chief executive assistant to Mayor Coleman A. Young, city of Detroit. Prior to becoming deputy mayor, he was director of the Center for Urban Studies and director of The Center for Black Studies at Wayne State University, and is currently on leave of absence from Wayne State where he is a professor in the School of Social Work. Professor Simmons earned his B.A. from the Detroit Institute of Technology. His M.S. and M.S.W. degrees were earned from Wayne State University.

Professor Simmons is currently chairman of the board of the Detroit Development Corporation, the Detroit Port Authority and the Northwest Activities Center of Detroit, Inc. He is also a member of the board of the United Foundation of Metropolitan Board.

Professor Simmons has provided leadership to various civic and business organizations, serving as executive director of the Mayor's Committee for Human Resources Development for the City of Detroit; assistant director of the Human Relations Commission for the city of Ann Arbor; consultant to the National League of Cities-U.S. Conference of Mayors; the National Advisory Council on Economic Opportunity and the National Advisory Commission on Manpower; chairman of the board of the Inner City Business Improvement Forum; board member of the Michigan Council for the Humanities; board member of the Council of University Institutes for Urban Affairs; trustee of the Detroit Metropolitan Fund and board member of the National Association for Community Development; chairman of Detroit's Charter Revision Commission; co-chairman of the Governor's Option Process Task Force and as vice chairman of the Michigan Commission on Manpower.

Professor Simmons, having lectured and taught at several universities over the past decade, delivered numerous addresses to a variety of national conferences and written extensively on community development and citizen participation in government, thoroughly understands the energy crisis facing our nation.

It is a pleasure for me to be here today representing the mayor of this fine renaissance city, Coleman A. Young.

It is really fine that you are dedicating this conference to the energy crisis confronting our nation. As you know, energy awareness is a vital concern, particularly to a city such as Detroit. Our very lives and livelihood depend on energy related industries such as the automobile industry.

There is no question that the wisdom you gentlemen bring with you will help us to look at not only how to develop better energy sources but also how to conserve energy, and that is very important to our everyday life. It gets down to such matters as insulating our homes and starting from there.

Again, welcome to the renaissance city on behalf of the Mayor and the entire city of Detroit.

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Energy Awareness Luncheon

Opening

In the ceremony at which a professional engineer receives his license to practice, he is required to pledge that when the occasion arises, he will put public service above all else. The officers and members of the National Society of Professional Engineers perceive that such a time has arisen.

Under the heading **"Speaking of Energy,"** you will find forceful statements by eight distinguished engineers on their perception of our energy problems. But for want of space and time, there would be 80,000 such statements.

NSPE is undertaking a nationwide commitment to communicate factual information to the public on energy issues — issues whose outcome will decide whether our children are able to enjoy the kind of prosperous, democratic lifestyle that we have enjoyed in our maturity. It is appropriate that this national effort should begin here in Detroit, for the problems that you in Detroit face are the problems and challenges that all Americans face. The wave is simply washed ashore here early on.

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Invocation

Rev. Nicholas Hood, Councilman, City of Detroit

Rev. Nicholas Hood is one of Detroit's spiritual and civic leaders. Since 1958 he has been the senior minister of Plymouth United Church of Christ (Congregational). He has served as minister at two other Congregational churches and is a former vice-moderator of Congregational Churches of the United States. In addition to his B.S. from Purdue University, his B.A. from North Central College, and his M.A. from Yale University, he holds honorary doctorates in divinity from Olivet College and the University of Chicago and in law and letters from North Central College and Purdue University.

A member of the Democratic Party for over 30 years, Rev. Hood is currently serving his fourth four-year term as a councilman. He has helped found two major housing developments in Detroit: the 230-unit Medical Center Courts, a $3.5-million complex aimed at low-to-moderate incomes, and the 450-unit Medical Center Village, an $11-million project suited to all income levels. He is also a founder of Cyprian Center, a facility for the treatment and training of mentally retarded persons.

Rev. Hood is chairman of the board of directors of Minister's Life and Casualty Insurance Company and vice-chairman of the United Negro College Fund's Michigan campaign. He is also a trustee of Hutzel Hospital in Detroit and a member of the board of the Michigan Association for Emotionally Disturbed Children and the Renaissance Heart Unit of the Michigan Heart Association.

Rev. Hood's other activities further reflect his commitment to social involvement. He served as president of the Nonprofit Housing Center affiliated with Urban America (which has since become a part of the National Urban Coalition) and as the U.S. representative to the 1972 World Conference on Nonprofit Housing. The previous year he participated in the Industrialized Housing Study Tour in Europe. From 1972 to 1974 he served on the Advisory Committee to the Federal National Mortgage Association. He was one of the founders of the Southern Christian Leadership Conference and has been active in the National Association for the Advancement of Colored People (NAACP), on the board of the New Orleans branch and as a member of the Detroit branch.

Almighty God, we pause now to recharge our spiritual batteries, thanking you for the energy that has brought us thus far. Ignite our spirits so that our minds might become like solar collectors, receiving and stirring your divine power so that we might continue to stir our minds. Grant us Lord, the tenacity to sustain and to withstand so that as the storms of our lives come and go, the power lines remain up and we don't suffer a spiritual blackout. We know, oh God, that with you, if we maintain our connections, your generator will never cease and we will never be faced with an energy crisis. Amen.

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Introduction of Speaker

John D. Selby, P.E., Chairman and President, Consumers Power Company

John D. Selby is president, chief executive officer, and chairman of the board of directors of Consumers Power Company. He joined the firm in 1975 as the president and a member of the board; in 1978 he was named its chief executive officer and the following year was elected chairman of the board. Before joining Consumers Power, he spent 29 years with General Electric Company, where he served in various executive capacities, including deputy manager of the Nuclear Energy Division.

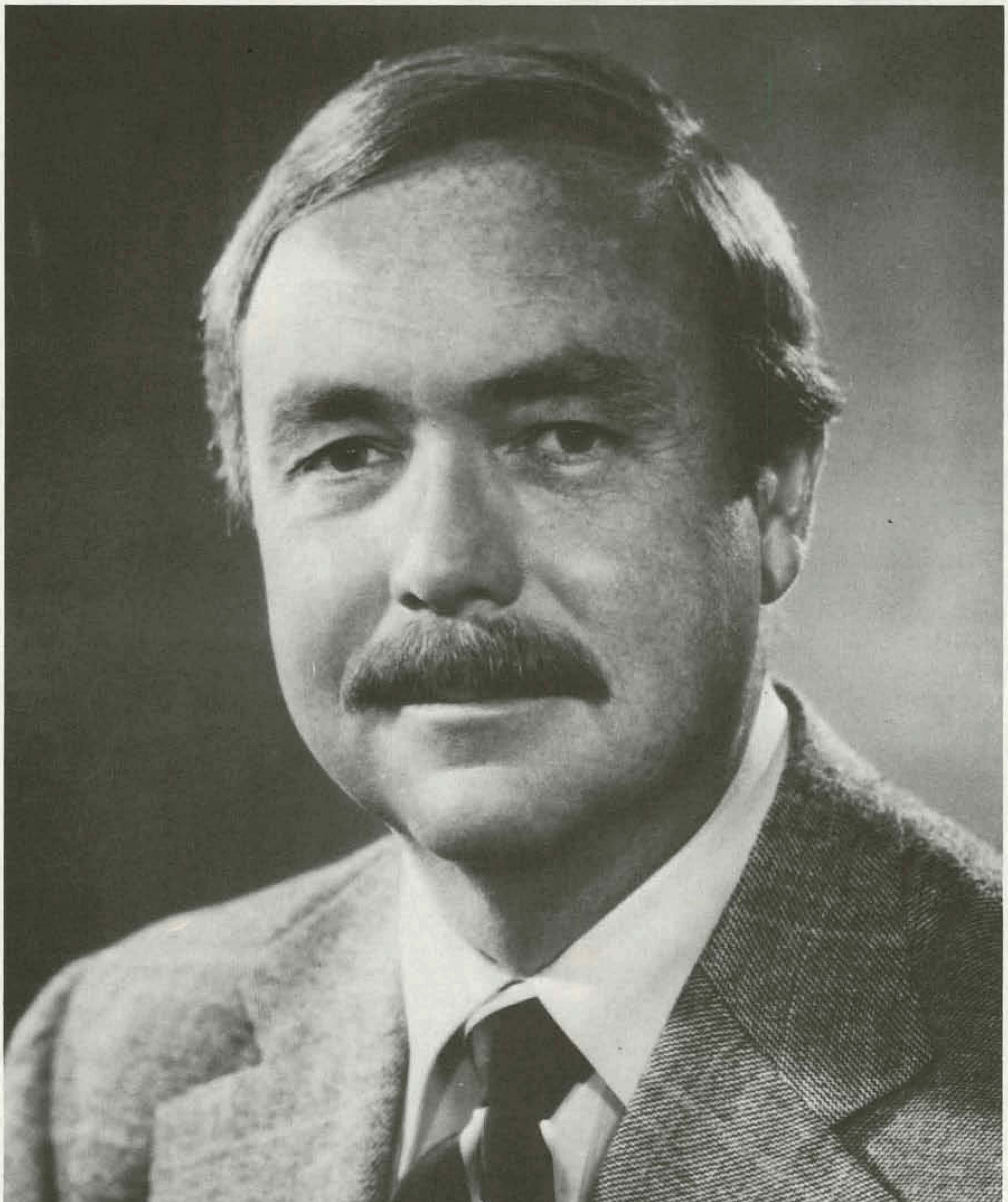
A registered professional engineer, Mr. Selby holds patents on fluid heat exchange equipment and power-generation systems. He is an engineering graduate of Iowa State University and studied business management at the Harvard University Business School. Mr. Selby is a member of the National Society of Professional Engineers, the American Society of Mechanical Engineers, the American Gas Associations Government Affairs Committee, and the board of directors of Edison Electric Institute, whose Policy Committee on Nuclear Power he chairs.

Mr. Selby is active civicly as well as professionally; he is a trustee of Jackson Community College and of the Jackson Foundation and is a member of the board of directors of the Atomic Industrial Forum, the Economic Club of Detroit, the Greater Jackson Chamber of Commerce, the Michigan Chamber of Commerce, and the United Way of Michigan.

Mr. Selby's distinguished career in energy-related industry has given him firsthand knowledge of the current energy crisis facing the United States.

In reviewing Mr. Randall's career, several points in my opinion are worth noting. First, when he moves into an organization, he moves and the organization moves. Second, when a devout Democratic like Lyndon Johnson names a Republican, Ken Randall, chairman of the FDIC, it tells me that he's sought out because of what he knows, not who he knows. And third, asked what he spent most of his time on after becoming chairman of the FDIC, Mr. Randall replied "an airplane." A big part of the job, he explained, is making sure that you understand what is happening in the real world, and the real world is not in Washington. To that I heartily agree.

I think that with this group of professional engineers, Mr. Randall's in the real world and we are anxious to have his perceptions about that world.



Kenneth A. Randall

Kenneth A. Randall, a former chairman of the Federal Deposit Insurance Corporation (FDIC), is currently president of The Conference Board, Inc., a New York-based research institution specializing in business economics and management experience. The Conference Board, which also maintains offices in Washington, D.C., Ottowa, Canada, and Brussels, Belgium, publishes numerous periodical and special reports on business and industry and conducts courses, conferences, and seminars in the United States, Canada, and Europe to allow its 4000 members to exchange ideas and keep abreast of the latest business developments.

Prior to his election to the presidency of The Conference Board in 1976, Mr. Randall served as chief executive officer of United Virginia Bankshares, Inc., which he joined in 1970 upon retiring from the chairmanship of the FDIC. At the time he joined United Virginia Bankshares, he was also serving as one of four bankers on the President's Commission on Financial Structure and Regulation, commonly called the Hunt Commission. The Hunt Commission's report, published in December 1971, continues to influence bank legislation and philosophy.

Appointed to the FDIC by President Johnson in 1964, Mr. Randall represented two firsts for the new president: he was Mr. Johnson's first Republican appointee and his first appointee not previously committed by the Kennedy administration. Fourteen months later, in a most unusual move, Democrat Johnson appointed Republican Randall chairman of the FDIC on the mutual understanding that partisanship would not influence either's view of the running of the regulatory body. Being appointed to the chair from the minority party, Mr. Randall found himself in a unique position. As he recalls, "the Democrats didn't know what I was and the Republicans treated me with suspicion. It was a great experience."

Mr. Randall's term on the FDIC followed sixteen years with the State Bank of Provo, Utah, during which time he advanced from the rank of part-time teller to president of the institution. He had entered college determined not to enter banking, the profession of both sides of the family for two prior generations. While a student at Brigham Young University, however, he reversed his position, becoming deeply interested in banking philosophy, and earned a B.S. in finance and banking and an M.S. in economics. Later he studied at Stonier Graduate School of Banking as well.

During his career Mr. Randall has provided leadership to a diversity of other organizations, serving as a director of Consolidated-Bathurst, Inc., Jaguar Rover Triumph, Inc., Northeast Bancorp, Inc., and Virginia Electric and Power Company; as a member of the Advisory Council on Japan-U.S. Economic Relations, the U.S. section of the European Community-United States Businessmen's Council, the Advisory Council of the Electric Power Research Institute, and the U.S. Business and Industry Advisory Committee to the Organization for Economic Cooperation and Development; and as a trustee of Mary Baldwin College and Independent College Funds of America, Inc.

Mr. Randall's distinguished career in banking and energy-related businesses, along with his current role as head of a business and economic research institute, uniquely qualifies him to speak on the economic and political urgency of our country's energy crisis.

Energy—Growth—Freedom

Luncheon address

Kenneth A. Randall, *President, The Conference Board, Inc.*, New York, NY

I have a fairly serious speech today, but I am reminded in looking at this audience and hearing the remarks by Pat and others, that what we're talking about is a sense of direction.

I have been told by your colleagues and by my close and very good friend Harry Bovay that we are living in the age of the engineer—an age characterized by creativity, growth, and improvement of the physical conditions of life. The evidence is all around us, particularly here in Detroit's Renaissance Center. Engineers and the technology they have created have had a most profound and beneficial impact on every aspect of the human condition.

But technology, like most of man's creations, is multifaceted, and if this is indeed the age of the engineer, it is also the age of risk—risk on a global scale.

Newton taught the world that for every force there is an opposite and equal force. It follows logically, then, that even within technology's power to create lies the capacity to destroy. Mankind has marveled over technology's creations since the birth of the industrial revolution, but now, for many reasons (some artificial and some real) attention is being focused on technology's potential for destruction.

Contemporary reaction to the concentrated focus on risk is predictable and human. Man is frightened. He is being told by many that technological innovation and industrial growth are destroying his environment and ravaging nonrenewable resources, and he fears that the inevitable consequence will be political upheaval and social chaos. It matters not if what he is being told is true, half true, or untrue. So long as he believes it and is frightened by it, he will be susceptible to suggestions as to how to protect himself.

Yet risk did not begin in this generation; it has been with man from the beginning, and he has learned that it is the price of human advancement. Man's fears notwithstanding, he recognizes the enormous benefits that technology has brought to him, and he has no desire to return to the cave and the loincloth or to the conditions prevailing in the early centuries of industrialization.

This is a quandary of major proportions, and it is further complicated by those who offer as a solution a peculiar philosophy having siren-like appeal. This philosophy, which has been attracting attention at the highest levels, is called zero growth.

Zero growth! What a beguiling solution. Freeze everything in place, then those who have will continue to have and will no longer need to fear that those below will destroy the world as they try to improve their lot. As for those who have not, they won't miss things that they've never had.

You and I, who have devoted our lives to creating, developing, and improving, have seen firsthand the rewards that growth yields to all of society, as opposed to the squalor and human misery that accompany stagnation. If we have paid any attention at all to the zero-growth creed, we have generally dismissed it as an absurdity. But we dismiss it at our peril, for there is a magnetic attraction to that philosophy, and it is working its spell in places where clear thinking and leadership are desperately needed.

In the context of this dilemma, let us examine the energy problem, for it is a classic case in point.

Growth has been our national goal since 1776, and energy has been our means to achieve growth. Six years ago our energy supply was severely disrupted and our continued growth was threatened. The problems of energy production and distribution are enormously complex, but they are manageable problems if we agree on what we wish to accomplish. The needed technology and managerial talent are available to supply us with the energy we must have to sustain our national growth.

The no-growth advocates have confused us, however, by proposing that we solve our energy problems not through innovation but by abandoning the goal. Growth is destroying the environment, they say. Stop growing and there will be no need for additional energy.

The result of this divisive proposal has been impotence at home and abroad. I need not remind you that three presidents have tried to forge a cohesive energy policy, yet little more than rhetoric has come of it. The only progress we have made in altering our energy consumption pattern has sprung from market forces (when government has permitted them to function) and from the common sense of people and of industries who have said: "I can't afford to pay more. I'll use less."

How to use energy to maintain the productive capacity of the developed world is the most confounding problem of our time. The problem will not yield to simplistic solutions, nor will the exploitation of fears and anxieties contribute to its solution. To deal with it, we must sort it out piece by piece, explain it rationally to the public, and act intelligently on the best information available. In doing so, it would be well to keep this in mind: if the United States is to provide jobs and economic well-being on only a sustaining base between now and the end of the century, our economy must grow by at least 2½% each year.

Today one can find any number of scenarios relating to our energy future. A particularly thoughtful one that has come to my attention was developed by the Electric Power Research Institute (EPRI).[1] It starts from the assumption that we must conserve our liquid hydrocarbons for industrial feedstock and for mobile fuels by converting much of our energy use to electricity and that we must find alternatives to petroleum and natural gas as fuels for electricity production.

This scenario raises questions that must be faced by the body politic, for if EPRI estimates are correct, many of the energy alternatives being proposed by others are, at best, political deceits. This is especially true of claims that we can develop rapidly the use of renewable resources to provide sufficient electricity to meet our needs.

According to EPRI, even with extensive conservation and greatly reduced economic growth, the demand for electricity will double or triple between now and the end of the century. In EPRI's view this estimate is conservative.

[1]Chauncey Starr (EPRI vice-chairman), "Energy Availability and Industrial Growth," presented to the Business Council, Hot Springs, Virginia, October 13, 1979.

If the demand for electricity doubles or triples in the next 20 years, how is it to be met? These projections are offered by EPRI:

- Coal now supplies 41% of our electricity Given environmental regulations and institutional and physical constraints on increasing our coal supplies, coal-produced electricity may realistically be limited to slightly more than double its current production, filling perhaps 45% of our total electricity consumption by the year 2000.
- Hydroelectricity provides about 11% of the generation output now, but it is doubtful that hydro can be doubled in the next 20 years. In EPRI's estimation, hydro's share of total electrical output in the year 2000 will have fallen to 7%.
- The EPRI scenario cites a 1979 report to the president which estimates the solar contribution (thermal, photovoltaic, and wind) to electrical output at the turn of the century.[2] Solar's share is projected in this federal report at 2 to 6% of the total, but EPRI cautions that this is based on very optimistic, and in some cases unrealistic, assumptions about the success of technical developments.

These sources—coal, hydro, and solar—will supply 55 to 60% of the minimum estimate of electricity to be consumed in the year 2000, EPRI believes. That leaves 40 to 45% to come from nuclear, synthetics, oil, and gas. But as EPRI points out: "Given our national need for liquid fuels for transportation and the strong federal policy to diminish their use for electricity generation, it is unlikely that synthetics and new oil and gas can be considered for electricity expansion purposes."[1] According to EPRI estimates, oil and gas will provide perhaps 13% of total electricity production by the year 2000, most of it for peaking power, while nuclear—the only remaining source—will have to make up the gap, which may be as much as 25% of all electricity consumed. To fill this gap will require the building of more than 200 nuclear plants. To provide growth above the sustaining level, we will need as many as 600 nuclear plants.

If all else were equal, the physical task alone of increasing our nuclear capacity to meet the projected demand would be herculean. But all else is not equal. Nuclear generation is wrapped in a shroud of myth, misunderstanding, and myopia; as a result, large numbers of people fear it, and it has become perhaps the most politically sensitive issue of our time.

Most of our trading partners in the world recognize that nuclear power is essential. The Venice Agreements among leaders of free-world nations call for its extended use and are very clear about its future development. Yet, at the very time that President Carter was in Venice participating in the Agreements, his own political party adopted a plank in its platform calling for the orderly phaseout of nuclear power plants in the United States. This poses a leadership dilemma for the president of the United States. I can't resist sharing with you a recent comment by Speaker of the House of Representatives "Tip" O'Neill, who said in a speech that "never again will the Congress allow for a strong President." That might be humorous in a wry sort of way if our problems weren't so desperately pressing.

If nuclear energy is essential to fuel the growth that we must have just to maintain a minimal economy, and if nuclear energy is so misunderstood that a fearful public may demand its curtailment, how are we to resolve this dilemma?

The zero-growth advocates have an easy answer: stop growing and we won't need nuclear energy! That answer is totally unacceptable unless we are willing to abandon the

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[2]Department of Energy, *Domestic Policy Review of Solar Energy,* TID-28834 (1979).

American dream and accept a radically different and far less palatable lifestyle. Our democracy and our freedom rest on the promise—fulfilled here as nowhere else in the world—that the pie will continue to expand and that everyone will have a chance at a larger piece of it. If the pie stops expanding, the inevitable result will be greater centralization of authority in order to allocate what remains of it. The freedom that we have struggled so long to preserve and that has yielded so many benefits will drain away inexorably.

I don't believe that the way to solve our problems is to stifle technology and growth. Quite the reverse, in fact. If our problems are to be solved in a manner compatible with our present lifestyle, it is technology that must bring forth the solutions. And technology cannot flower in a stagnant economy.

But before we can capitalize on the curative powers of technology, we must address man's continuing fear of it, for therein lies the very heart of our dilemma. Ever since man crawled out of the primal slime, he has been intent on improving his lot, making things easier for himself, advancing and prospering. After he has achieved so much, it must be a fundamental emotion indeed that would lead him to turn back. That fundamental emotion is fear, created by technological advances so rapid and complex that large numbers of people feel unable to absorb and comprehend the consequences. If you listen closely to the zero-growth advocates, the antinuclearists, the environmentalists, and a host of others, you will hear them saying: "We don't really understand your technology, but it's very powerful and we're afraid that it might get out of hand and destroy our world."

If I am right, then how do we deal with fear? I believe that we need to turn the light of understanding on technology. I believe that our only hope for continued growth is to remove the barriers erected by fear and that we can accomplish this only through a vastly expanded program of public information and education directed at all levels of our society.

I am not alone in this belief. Let me share with you a particularly well stated synopsis of the problem by D. Allan Bromley, Henry Ford II Professor of Physics at Yale University. In an analysis of facts and myths surrounding nuclear energy, he addresses the antinuclear movement:

> Those of us in the nuclear field have been extremely remiss in not taking much more time and spending much more effort in explaining the advantages and disadvantages of nuclear energy to the public. By failing to do so, we have left the way wide open for substantial exaggeration and misinformation on the part of those who, for whatever reason, are determined to eliminate the nuclear option in our national energy policies. It is my own conviction that the great majority of the members of the antinuclear movement are perfectly well-intentioned, concerned, and on the whole, better-than-average educated individuals concerned about what they perceive to be unwarranted risks associated with nuclear energy.[3]

I want to leave you today with a challenge that is best comprehended if I present it in two parts. First, I believe that we must illuminate technology so that the public can see and understand it. We the members of the scientific and engineering community and the managers of enterprises that utilize technology must take responsibility for this educational effort, because no one knows better than we the ratio of benefits to risks.

We must take the public's fears seriously, for they are a serious matter. We must share our knowledge with the public and respond candidly to their concerns. When their fears are

[3]"Energies of the Future," to appear in a forthcoming journal, *Technology and Society.*

justified, we must reduce the risks to acceptable levels; when their fears are unjustified, we must patiently explain where they are wrong.

Second, we must at the same time work to expand the public's vision, which at present is being focused too narrowly on technology's risks. We must help people to understand that unbridled pursuit of a risk-free life also carries the seeds of destruction—destruction of freedom itself.

Man's inventive genius and desire to improve himself are natural and powerful motivators that depend for fulfillment on freedom to grow. Only by the imposition of stern and authoritarian regulation of human life can those motivators be stifled. Marx and Lenin understood man's yearning for growth. The appeal of the Socialist utopia that they envisioned was the promise of abundance for all. When abundance failed to materialize and even the hope of it died, the dream of utopia became a nightmare of repression.

You and I must help our fellow Americans to understand that technology, economic growth, and freedom are inseparable; that to destroy one is to destroy them all. In my mind, that is the risk that is totally unacceptable.

I am an optimist by nature, with an abiding faith in the common sense of the American people. When they fully understand a problem, they come to the right conclusions and work at solutions with enthusiasm. I believe that Americans want to understand technology. They recognized its promise long ago, they embraced and supported it, and they have fully enjoyed its many fruits. They have no desire to retreat from it, but neither do they wish to live in fear of it. They are ready as never before to have it explained candidly, in terms they can understand, so that they can assess for themselves the risks and rewards that it entails.

My challenge to you today, then, is to use your expertise to help broaden the public's perspective of technology and economic growth. It is an urgent challenge, and nothing less than freedom is at stake. You and I possess the knowledge that the public needs to make an intelligent assessment. It will be tragic indeed if, by failing to share it, we permit unfounded fears to destroy freedom.

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Energy Seminar

F. S. Patton, P.E.

Program Chairman

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During the past six years, Mr. Patton has been active in energy issues and has spoken in many parts of the country. He is a member of the **NSPE Energy Committee** and is the NSPE representative on the Coordinating Committee on Energy, which represents 22 technical and engineering societies.

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Keynote Commentary

F. S. Patton, P.E., *Director of Engineering, Union Carbide Corporation, Nuclear Division*, Oak Ridge, TN

My purpose is to outline briefly global circumstances pertinent to the feature presentations my colleagues will make to you on the prospects for oil and gas, coal, nuclear power, and solar and biomass in the United States.

We live in an era that has been entitled the "Age of Petroleum". While at the present time approximately 45 percent of all global energy is derived from naturally occurring liquid petroleum,[1] it can be argued that a far greater fraction of man's vital activities are dependent on this natural resource.

Let us reflect:

All air transportation is dependent on naturally occurring petroleum liquids.

Essentially all maritime transportation is so dependent.

The vast proportion of all modern land transportation uses petroleum liquids as fuels.

Even the movement of coal is overwhelmingly based on diesel fuel.

The production of food is heavily based on oil-fueled mechanized agriculture and fertilizers derived from natural gas.

Today, over one-third of all fibers and over two-thirds of all rubber are synthetics dependent on petroleum-based chemicals. Indeed, the global production of petroleum based plastics is about four times the production of aluminum.[2]

Many medicines and pesticides are manufactured from petroleum chemicals.

This "Age of Petroleum" really achieved its dominance within the lifetime of most of the audience. An attempt was made to summarize the cumulative total historical consumption of oil prior to the beginning of World War II, and the rough approximation thereby arrived at from available records over the centuries was about *33* billion barrels. Our globe now consumes over *23 billion barrels in a single year.*

23 billion barrels a year = 63 million barrels a day = 30,000 gallons per second

These 30,000 gallons of oil per second are the pulsing life-blood of the planet sustaining its teeming 4.5 billion people.

The last 30 years has been a period of massive exploitation of this remarkable resource. If we look back to 1950, there were then some 2.5 billion people on earth, and their total

[1] Associated natural gas is the source of an additional 18 percent of global energy.
[2] Christopher Flavin, "Worldwatch Paper 36," Worldwatch Institute, Washington, D.C., April 1980.

consumption of petroleum liquids at that time was about 10 million barrels per day. Global oil consumption has increased more than *sixfold* in the short period of 30 years. In the United States in 1980, with a population of some 220 million — 5 percent of the earth's current population (of 4.5 billion) — we are consuming *about 18 million barrels of oil per day,* nearly *twice* what the 1950 global population of 2.5 billion was consuming.

What are the characteristics that have made petroleum so attractive as to bring about such an overwhelming global dependency in such a short period?

A ton of oil has about 50 percent more energy than a ton of coal and usually contains far less in the way of pollutants.

Oil is a liquid over a broad span of temperatures and is not corrosive to most common materials; it can be safely and cheaply transported over long distances.

A gallon of gasoline has about 50 percent more energy than a gallon of ethyl alcohol and about twice as much energy as a gallon of methyl alcohol (wood alcohol). Thus, if you were to design a car to run on methyl alcohol rather than gasoline, it would need to have a fuel tank about twice as large to be equivalent.

Oil has been cheap.

A consensus order-of-magnitude approximation of the total global endowment of conventional oil that could be recovered by reasonable means is *2000* billion barrels. About *1100* billion barrels have been found and *900 - 1000* billion barrels are thought to remain which have not yet been found.

Of the *1100* billion barrels that have been found, about *450* billion barrels have been extracted and consumed. In general, the most accessible oil deposits were located and exploited first. Some of this easy oil was pumped out of the ground at costs as small as a penny per gallon. Indeed, it can still be gotten out of the ground and on board ship in Saudi Arabia for such low cost. Oil from sources such as oil-shale and synfuels will not be measured in pennies but in dollars per gallon.

The capitalist democracies (United States, Western Europe, Japan, Canada, and Australia) established an industrial cornucopia based on *cheap petroleum* which grew at an astounding rate through the 1950's and 60's. Their demand for oil and raw materials far outstripped their domestic resources, and a vast international trade based on the flow to the northern industrial nations of petroleum and industrial raw materials from over 100 underdeveloped nations, located largely in the earth's tropical and southern regions, sprang up. Payment for these essentials was in the form of finished manufactured products and cereal grains (wheat, oats, corn, rye, rice, etc., which are the source of about three-fourths of the total calories in the world's food supply).

The great growth in oil and natural gas based technology, material goods, and food production was accompanied by — and it can be argued, made possible — an astounding increase in the earth's population. In the period of 1950-1980, world population increased about 75 percent (2.5 billion to 4.5 billion). The increase is now at a pace of 85 million more people on earth as each additional year passes. It is projected that the earth's population will reach 6 to 7 billion by the year 2000. There are already hundreds of millions of people living who could not be sustained at pre-1950 levels of technology and oil and gas production. While the earth's oil production rates are not yet limited by resource depletion, the political and economic incentives of the oil exporting countries are such that there is reason to believe that global oil production may never be much above present levels and that thereby, *on a per capita basis, production of oil for the earth peaked in the late seventies*

(5.3 barrels per person per year in 1977) and is now declining. There is also concern that the per capita production of the vital cereal grains may have peaked in the same period (about 750 pounds per person per year in 1977). In the last 5 years, world grain *production rose 12 percent but consumption rose 15 percent;* global grain reserves dropped over 50 million tons in this period.

As previously noted, the earth's present production of oil is approximately 63 million barrels per day; about 14 million barrels per day are collectively produced in the capitalist democracies (U.S.A., Western Europe, Japan, Canada, Australia)...sometimes called the "First World"; and about 14 million barrels per day are also collectively produced in the Communist group of nations (U.S.S.R., Eastern Europe, China)...sometimes called the "Second World". The other 35 million barrels per day are produced in the oil exporting nations of the block of over 100 underdeveloped nonaligned countries, often referred to as the "Third World"

The Capitalist "First World" and the Communist "Second World" each produce *14* million barrels of oil per day, but the Communist nations as a group consume only *13* million barrels of oil per day, while the Capitalist nations as a group consume about *40* million barrels per day; the difference of *26-28* million barrels per day being imported from the oil producing nations of the underdeveloped "Third World" block. Further, while oil reserves in the Communist regions are only 10-15 percent depleted, conventional oil reserves in the Capitalist "First World" areas — that can be economically recovered by current technology — are about 50 percent depleted.

To supply the tremendous demand for imported oil from the "Third World", the seaborne transport of oil has become the earth's largest item of trade constituting near one-fourth of all international commerce. Approximately 17 million barrels per day must pass out of the Persian Gulf through the narrow Straits of Hormuz to partially meet the needs of the United States, Western Europe, and Japan. A counter-flow of high technology machinery, finished luxury products, and foods of commensurate value is required to pay for this oil.

It must be recognized that a great number of poor "Third World" nations have no oil or gas deposits, no coal reserves, and no uranium. Their energy requirements must be met by importing oil or depleting their forest lands for firewood. These poor underdeveloped nations are the principal consumers of kerosene; it is used for lighting and cooking. As oil prices have gone up, in desperation, their people have turned to a greater use of firewood, and depletion of their forest lands has accelerated with potential deleterious ecological impact for the whole earth. It is estimated that the globe now has only about half as much woodland as in 1950.

This vast production of naturally occurring conventional oil which sustains the very existence of hundreds of millions of the earth's 2 billion poor and supports the 700 million citizens of the "First World" capitalist democracies with the highest living standards ever known is essentially an irreplaceable resource. It has been estimated that the equivalent of *60 thousand years of geologic time was required for nature to produce the amount of oil now consumed globally in a single day.*

Over a 25 year period spanning the 1950's, 60's, and early 70's, global oil production grew about 7 percent per year, global economic growth averaged about 4 percent per year, while global population growth was about 2 percent per year.[3] Thus, in an aggregate way,

[3] Lester R. Brown, "Worldwatch Paper 29," Worldwatch Institute, Washington, D.C., May 1979.

that period might be characterized as one of betterment for the bulk of mankind.

But now, *with a global system overwhelmingly dependent on conventional oil, we are entering a period of no-growth in oil production while population growth rate continues at only a slightly diminished pace.* There is considerable evidence that the long-term strategy of the consortium of oil exporting countries is to hold constant, or even diminish the quantities of petroleum available for sale in the international market, while periodically increasing prices. While such a prospect may still allow the more successful element of the capitalist democracies to maintain themselves in prosperity for several decades, little hope of improving living standards is offered the underprivileged and the half of the world's people who live in the poor countries. The capitalist democracies are the premier source of technology; less than 2 percent of all patents originate in the third world. *New energy technologies and energy conservation in the First World are essential.*

Thoughtful and farsighted authorities taking note of the population explosion recognized early in the 1950's that the earth's oil and gas reserves were finite and that other energy technologies would have to be developed to avoid a future energy and food disaster. A major strategy was to electrify the economies of the industrial nations, concurrently developing nuclear energy. The expectation was that coal and nuclear energy would ultimately assume dominant roles in the production of electricity as petroleum reserves diminished and oil became more expensive. The preponderance of *known major global resources of coal are in the northern hemisphere.* Further, it was appreciated that the underdeveloped nations of the earth's tropical and southern regions lacked the technological prowess to make early, large scale use of nuclear power; however, petroleum based applications, which are far simpler, could be extensively employed by *the underdeveloped nations.*Thus as envisioned, the steady growth of electricity produced from coal and nuclear power in the northern industrial nations would diminish their demands on oil, and thereby, allow increased petroleum energy usage in the underdeveloped nations whose growing populations are demanding higher living standards.

However, the growth of electricity production in the capitalist democracies has fallen far short of the projected pace. A principal cause of the drastically diminished growth of coal and nuclear fueled electric power is the effective resistance of opposition movements in the capitalist democracies, most particularly in the United States. No significant opposition has arisen in the Communist "Second World".

The issue is in doubt as to whether the energy supplies to avoid malnutrition and poverty for hundreds of millions will be available at affordable prices over the critical decades of the eighties and nineties.

The United States circumstances are:

> With about 5 percent of the earth's inhabitants, it consumes about 27 percent of the earth's energy production and *over 30 percent of all global raw materials* production.
>
> It consumes nearly 28 percent of the earth's annual production of oil but by placing vast areas of federal lands off-limits and by disincentives to exploration has seen its own proven reserves dwindle to 5 percent of the earth's total.
>
> It consumes its proven natural gas reserves at a rate that is about 38 percent of the earth's production, while by the same disincentives as for oil, has seen its proven reserves dwindle to 8 percent of the earth's total.

Over 70 percent of U.S. energy is from oil and gas.

It has about one-third of the earth's coal reserves but only 21 percent of its energy is from coal.

United States' economic history in the post World War II period has been characterized by a rough relationship between energy consumption and the growth of jobs and income. If we examine the decade of the 1970's, our population grew by 20 million people, actual gross national product (in constant 1972 dollars) increased 30 percent, while the number of employed increased about 20 percent, and *the utilization of energy increased nearly 20 percent.*

It is of utmost importance to note that total *domestic* energy production in the United States has remained roughly constant throughout the decade; essentially *all the net increase in energy consumption which fueled the expanded income and growth of jobs resulted from imported energy in the form of foreign oil and a small amount of Canadian gas.* This circumstance of the United States producing no more energy within its own borders in 1979 than in 1970 is the resultant of the increase in nuclear and coal being less than the loss in natural gas production; oil production is now about the same as in 1970 due to the North Slope Alaskan fields achieving full production.

The projection for the coming decade is that *U.S. population will increase even more than the addition of 20 million that occurred in the seventies.* It would follow that if the currently prevailing level of affluence is to be sustained, the growth in gross national product and the availability of jobs must, at a minimum, approach that of the seventies. In like manner, the rate of growth of energy consumption, less that saved by gains in conservation, must approach that of the seventies.

Where is this additional energy needed for the eighties going to come from? It is clear that U.S. national strategy must be, as stated in the NSPE Energy Policy:

"All economically feasible domestic energy options must be developed, coupled with a vigorous long-term effort on energy conservation."

The research and development of new energy technologies must be encouraged; a sustantial emergency petroleum reserve is a necesssity; a better balance must be achieved between environmental benefits and their costs; price controls on oil and gas should be removed; counterproductive regulations need to be ameliorated or eliminated.

Public lands need to be opened up for exploration. At the present time, the federal government owns over one-third of all U.S. land, but only 13 percent of this land is leased for oil and gas operation, with the result that *only about 7 percent of U.S. oil and gas production is from this federal land while 93 percent of production is from private lands and offshore leases.* The United States Geological Survey estimates that nearly *40 percent* of the nation's undiscovered oil and gas is on the federal lands.

Some may argue that opening up the federal lands would result in the short-term extension of a no-longer tenable life-style at the price of consuming the inheritance of future generations. *But our nation is extremely vulnerable now because of an overdependence on foreign oil.* We must use the years of the eighties for the vigorous development of new energy technologies to sustain us in the long-term, else future Americans will indeed have cause to look askance at our generation.

A good start has been made on energy conservation, and now we need to put comparable emphasis on increasing domestic energy production — *increasing America's energy production from its own resources is the thrust of this conference.*

The National Society of Professional Engineers is confident, that with the majority of our citizens united in common purpose, the job will be done.

H. E. Bovay, Jr., P.E.

Chairman, NSPE Energy Committee

H. E.(Harry) Bovay, Jr., is chairman of the board and chief executive officer of Bovay Engineers, Inc., a consulting firm handling engineering assignments throughout the world. He holds the degree of Civil Engineer from Cornell University. A registered professional engineer in 17 states, Mr. Bovay has long been active in the National Society of Professional Engineers: the current chairman of the **NSPE Energy Committee**, he has served the society as president on the national and the state (Texas) levels, as vice-president of the Southwestern Region, and as chairman of the Professional Engineers in Private Practice (a practice division of NSPE).

Mr. Bovay is active in other professional societies as well. He is a fellow and life member of the American Society of Civil Engineers and currently serves on its National Energy Policy Committee. He is also a member of the Energy Advisory Council, Planning and Design Division, of the American Road & Transportation Builders Association.

In addition to his professional activities, Mr. Bovay is involved in much civic work. He has worked for United Fund drives for years; he has served as a director of the Houston Chamber of Commerce; and he has received two of scouting's highest medals for his long and valuable service to the organization.

Mr. Bovay's article "Global Resources Outlook" earned him the Society of American Military Engineers' prestigious Toulmin Medal as the best article to appear in their journal *The Military Engineer* in 1977. His numerous energy-related activities, including the chairmanship of the **NSPE Energy Committee**, indicate his prominence in the field.

Past management of our energy resources by federal regulators has clearly demonstrated the need for an energy strategy that recognizes the fundamental economic realities and that is based on the efficiency of the marketplace and the productivity of private enterprise.

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The Future of Oil and Gas: 1980 and Beyond

H. E. Bovay, Jr., ***Chairman of the Board and Chief Executive Officer, Bovay Engineers, Inc.***, Richland, WA

The last 20 years of this century will be a period of transition from a petroleum-based economy to an energy-diversified one. The United States must find the means to manage this transition successfully if we are to maintain a reasonable level of growth, guarantee a healthy economic climate, and ensure our national security in a world scrambling for vital oil and gas resources. Creditable long-range energy projections indicate that the U.S. demand for energy during this period will likely continue to call for substantial imports of petroleum (Fig. 1). In view of this critical transition and our heavy dependence on foreign oil, I would like to touch on some of the major changes on the horizon and the actions that are needed.

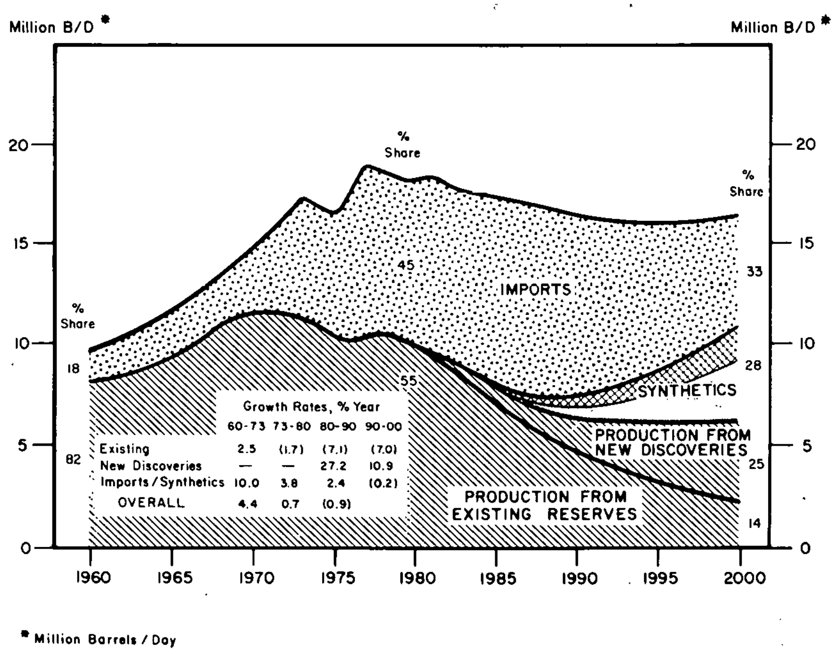

Fig. 1. U.S. oil supply. Source: Exxon Co., "USA's Energy Outlook, 1980-2000" (1979).

Many companies and government agencies regularly publish independently prepared long-range energy projections in order to inform various groups of the supply-demand outlook. These projections generally agree on the significant energy sources available to the United States both domestically and from imports. Such studies are useful in portraying the implications of the energy transition facing not only the United States but all nations who have historically been dependent on readily available sources of petroleum hydrocarbons for use as fuels and raw materials to support economic growth and industrialization. Generally speaking, energy sources can be divided into two groups with respect to end use: one group requires liquid and gaseous fuels, whereas the other group uses solid or other fuels to generate steam and electricity. Figure 2 shows the U.S. energy supply by types of fuel. In 1980, the needed oil and gas constitute 72% of our energy supply; by the year 2000, their share will be 49%. This 23% reduction will be picked up by coal, nuclear, and other sources.

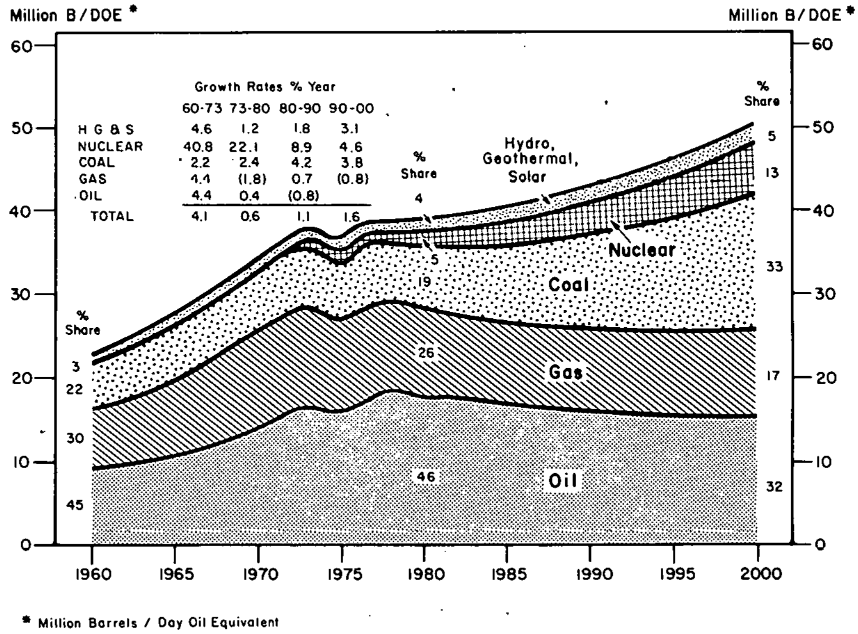

Fig. 2. U.S. energy supply. Source: Exxon Co., "USA's Energy Outlook, 1980-2000" (1979).

Figure 3 shows the consumption of energy resources in each sector: household and commercial, industrial (for power and raw material), transportation, and electric utilities. As I study this figure, I remember the words of Dr. Eugene Schoch, who was a professor at the University of Texas. In 1946, he said that we should not be burning natural gas and oil under boilers but should be saving it for future generations for production of food and fiber. I think the longer you look at this figure, the more you will agree.

In Figure 4, which shows the U.S. energy outlook by fuel consumed, you'll notice that in 1980, we imported 26% of our total energy supply as oil and gas and obtained 46% from domestic oil and gas. New discoveries, synthetic fuels, coal, nuclear, and other sources made up the remaining 28%. In the year 2000, 13% of our energy supply will be imported oil and gas, 11% will be domestic oil and gas, and 76% will need to come from new discoveries, synfuels, coal, nuclear, and other sources. Imports will have been cut in half, domestic oil and gas cut to a quarter, and the difference picked up by other domestic fuels.

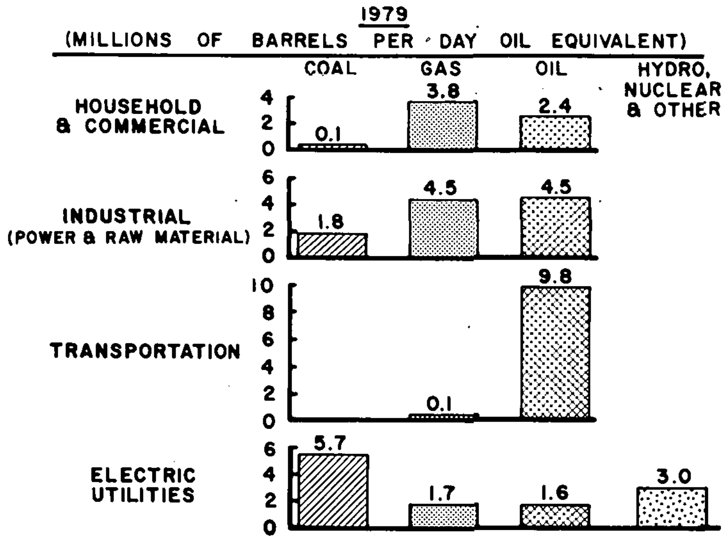

Fig. 3. Energy consumption by source and sector. Source: Texaco "Gasohol."

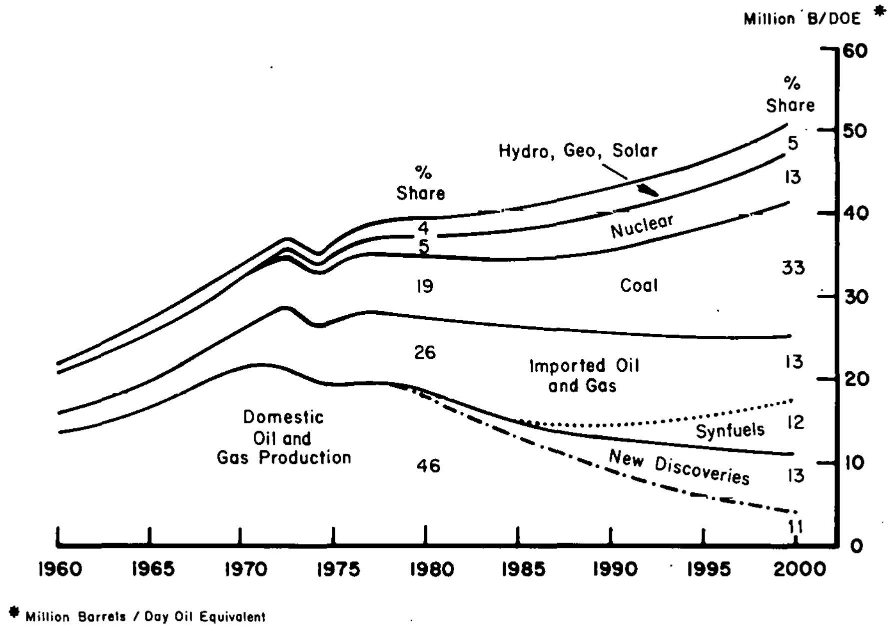

Fig. 4. U.S. energy outlook by fuel consumed. Source: Exxon, "Synthetic Fuels."

Let me state, too, that the top curve, or the total energy, already takes into account all the reductions due to conservation. Our country is, and will remain, woefully deficient in domestic oil production; the importation of about 8 million barrels daily, or 45% of current consumption, is necessary to supplement domestic production. Despite all that we may be able to accomplish to increase production of conventional and nonconventional forms of energy, imports are projected to constitute about 33% of the U.S. supply in the year 2000.

Furthermore, natural-gas imports presently amount to about 1.4 trillion cubic feet per year, or 7% of current consumption, and such imports will likely double in volume by the year 2000, to a level of 16% of total supply. Declining production in the United States will be supplemented by natural gas from Alaska and by synthetic gas from the coal gasification industry, but despite these measures, substantial imports will be required to meet projected demands. So we must reluctantly conclude that U.S. dependence on foreign sources will remain high during the transition period ahead unless major new petroleum deposits are discovered within the continental and offshore boundaries of the United States. The fact remains, however, that we're not discovering new deposits at the rate we used to and we're not keeping up with our rate of consumption.

The outlook for petroleum resources to meet the world's possible future requirements gives little room for comfort. The right column of Table 1 shows the years of fossil-fuel reserves remaining for the free world and the rest of the world; if we continue at current consumption rates, the years of supply for us or for anyone else are astoundingly short.

Table 1. World fossil fuel reserves

Billions of barrels oil equivalent

Fuel	Reserves	Production	Years of supply
Natural gas[a]			
Free world	273	6	43
Rest of world	166	3	53
Petroleum[a]			
Free world	547	17	32
Rest of world	94	5	19
Coal[b]			
Free world	1458	5	292
Rest of world	980	7	140
Total			
Free World	2278	28	81
Rest of world	1240	15	83

[a] Reserves as of January 1, 1979; production in 1978.
[b] Reserves as of January 1, 1977; production in 1977.
Source: *Oil and Gas Journal*; Department of Energy, *World Energy Survey*.

Over 100 developing nations are striving for rapid economic growth. The CIA has studied the outlook for world oil production and projects that the currently peaking output will commence to decline during the 1980s. This outlook is indeed grim and foreshadows head-on competition for Middle Eastern oil; the result will be strained relations among industrialized and developing nations. Presently, world production of petroleum amounts to about 62 million barrels daily, of which one-half is supplied by the Organization of Petroleum Exporting Countries (OPEC) cartel of 13 nations (Fig. 5). This map represents the world's published, proven oil reserves: the Middle East furnishes 32.66% of the total; the communist countries, 26.31%; North America, 11.2%; and the balance of the free world, 19.83%.

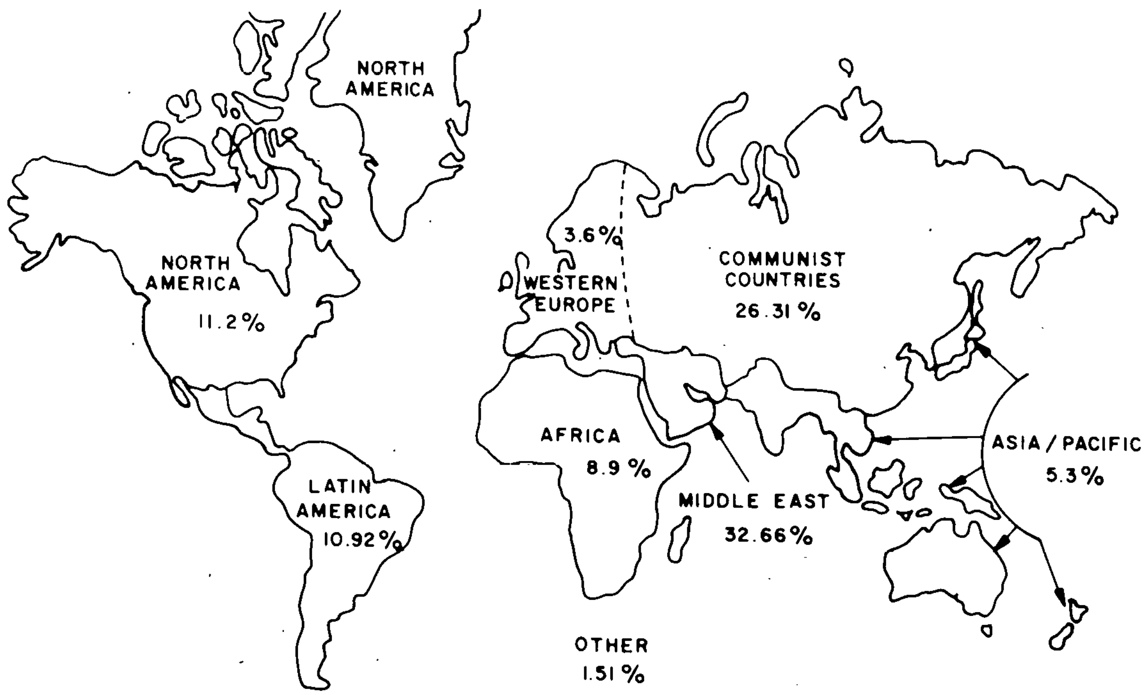

Fig. 5. World oil reserves. Source: derived from M. King Hubbert, Congressional Research Services, 1977.

Non-OPEC nations, including the communist bloc, buy most of the OPEC oil to meet their energy requirements. The 1973 Arab oil embargo dramatically emphasized global dependence on the Middle East. Senator Henry Jackson has predicted that an oil supply interruption of major magnitude is a virtual certainty some time during the next decade. Current events are a grim reminder of this prophecy and of the need to reduce U.S. dependence on foreign oil.

Let us briefly consider the possible consequences of this dependence. Most of the Arab OPEC nations have historically been steeped in high political turmoil and risk. In the last three decades, for example, the Middle East has suffered a half-dozen wars, a dozen revolutions, and countless assassination attempts and territorial disputes. The political instability in the region, stemming from land disputes with the new Israeli nation, reflects deep-seated problems of a dangerous order. Our overdependence on the area obviously leaves us vulnerable to an interruption of supply and to exorbitant price increases by the cartel. A recent Library of Commerce study showed, for example, that a cutback of only two million of the approximately eight million barrels of oil we import each day could severely affect the nation's economic growth, could cause further inflation, and could substantially increase the cost of all petroleum products, such as gasoline, to U.S. consumers.[1]

Moreover, we are already seeing the impact of the steadily rising costs of imports on the value of the dollar. The U.S. balance of trade will suffer from the payment overseas of some $60 billion this year for oil imports. Our economic strength is thus being eroded at a rapid rate by the lack of adequate levels of domestic production. I predict that every year

[1]A speech by Lewis D. Conta, engineer in residence at the Engineering Society Commission on Energy, Inc., "The Next Decade in Liquid Fuels" (April 1979).

for the next three years, you're going to see inflation at a rate greater than 10%—maybe up to 25%—mostly because of this economic erosion.

Finally, another major consequence of our dependence on imported oil lies in the severe strain that would be put on diplomatic relations with friendly nations if oil supplies were disrupted again. Since the United States, Japan, and Western Europe are by far the world's largest oil importers, any curtailment of OPEC supplies would have to be managed as a cooperative effort to ensure mutual security of national interests. The noncommunist powers would also have to give fair consideration to the less-developed nations in time of crisis and short supply, in order to maintain world stability and to allow a peaceful solution to disruptions of supply. Undoubtedly, the need, during the transition, for diplomatic relations with nations friendly to us will call for great statesmanship on the part of the United States, both at home and abroad.

If oil imports pose such a threat to U.S. security, we might speculate as to why so little has been done to remedy the domestic supply situation during the past decade. Early warnings of the dilemma now facing the United States were well publicized, but they went unheeded in the formulation of domestic policy until a national emergency arose at the time of the Arab oil embargo. Then it became necessary for the federal government to mandate regulations and controls to manage a short-term shortage. Now, with adequate world supplies available, we find a massive bureaucracy in place to regulate the energy business in the public interest. It is my opinion that economic and technical issues best resolved in the market place were taken over by the federal government for political reasons, with the poor results we see today. Had we allowed the free-market system to function following the embargo, world supplies would again be in balanced demand and at the lowest reasonable costs. The proliferation of government rules, regulations, and controls, together with the punitive taxes levied on oil production, has indeed created a climate in which it is difficult for private enterprise to expand domestic production of both conventional and nonconventional fuels.

The absence of a sound federal energy policy has been costly to the American taxpayer. The Department of Energy alone had a first-year budget of an astounding $10.4 billion, which was greater than the profits of the seven largest oil companies. Imagine the beneficial effect on new production had these funds been channeled into the energy industries for investment in new resources.

Our government is now beginning to realize the mistakes of its energy meddling and is taking long-overdue measures to allow fuel costs to rise to their market value and to develop programs for the development of alternative energy sources. Unfortunately, though, no matter what steps we begin to take now to change our fuel-consumption trends, conventional oil and gas will continue to dominate our nation's supply-demand mix for at least the remainder of this decade and probably well into the next. Coal and nuclear energy are the only practicable means to reduce dependence on foreign oil and to offset the projected decline in domestic petroleum production. Even so, the use of coal and nuclear energy is deeply mired in environmental and political concerns which must be resolved before these resources can fulfill their potential for use.

An increase in domestic petroleum production by exploration and development of new areas will be difficult to achieve. However, significant new discoveries cannot be ruled out, as evidenced by Alaska North Slope production, the Tuscaloosa Trend (Louisiana), the Overthrust Belt (Wyoming), the Santa Barbara Channel (California), and the recent

Hibernia discovery off the shore of Newfoundland. The number of drilling rigs in operation worldwide has reached an all-time high and is increasing steadily in the search for new supplies. Yet, to arrest the decline in U.S. resources and merely to hold domestic production of oil and gas at current levels until 1990, studies show, the industry will have to drill about twice as many wells as are now being drilled.[2] However, the optimistic drilling forecast, which assumes lenient government regulations and optimum drilling conditions, predicts only 75% success in maintaining current productivity over the next six years. Decontrol of prices will free additional capital necessary for further exploration and development of new frontier areas. Most projections indicate, however, that about the most the United States can optimistically hope to discover during the transition would maintain production at the current level of 10 million barrels per day. To maintain this level of production in the late 1980s will require that almost 4 billion barrels of oil be discovered each year between now and then. This is a large order, since in only one year during the past 30 years has more than 3 billion barrels of reserves been found.

The probability of increasing domestic production of oil and gas does not look reassuring as an early solution to energy independence. This brings us to conservation and its place in energy planning. Conservation has an important role in determining the level of imports. While conservation is not technically a form of energy, it can have a substantial impact in the short term because efficiency measures can be quickly accomplished. The development of new domestic energy sources requires a long lead time compared with that of conservation measures. The efficient use of oil and gas is clearly under way and will be a key factor in holding down imports in the short term. The engineering community is particularly well equipped to make significant contributions in this area. Indeed, one of the most dramatic conservation measures will result from the planned improvement in the efficiency of the automobile engine, which could reduce present gasoline demand by approximately 3 million barrels daily in 1990. In 1970, new passenger cars averaged 13.5 miles per gallon; the 1980 models are to average 17.5 miles per gallon by EPA test methods, and the average will increase to 26 miles per gallon by 1990. Conservation in all forms will undoubtedly challenge our abilities to imagine and to innovate in the application of basic engineering principles. However, despite these technological improvements, the general public must begin to conserve now as a new way of life; otherwise, forced curtailments can be expected in the future, perhaps causing dramatic changes in the way we live and work. There are many encouraging signs that conservation awareness is affecting all forms of energy consumption, however.

A public perception of the necessity to conserve began about 1973, as shown by the deviation from historic consumption trends. On the basis of this deviation from trends, in 1980 we expect to save about 2 million barrels per day in each end-use sector (residential-commercial, transportation, and industrial-nonenergy), or a total of 6 million barrels per day. In the year 2000, we think we will save 7 million per day in the residential-commercial sector, 12 million per day in transportation, and 8 million per day in industrial-nonenergy, or a total of 27 million barrels per day (Fig. 6). These figures reflect the current deviation from historic trends, of course. Figure 7 clearly shows the energy savings from conservation

[2] "U.S. Petroleum Industry Will Face a Monumental Task in Next Decade," *Oil Gas J.* 77 (46), 170 (1979).

as opposed to consumption if historic trends continue. The top line is the projection of the trends the lower line shows what the conservation efforts are going to accomplish. These numbers, incidentially, are the same numbers shown in the other figures, so these curves track the previous graphs.

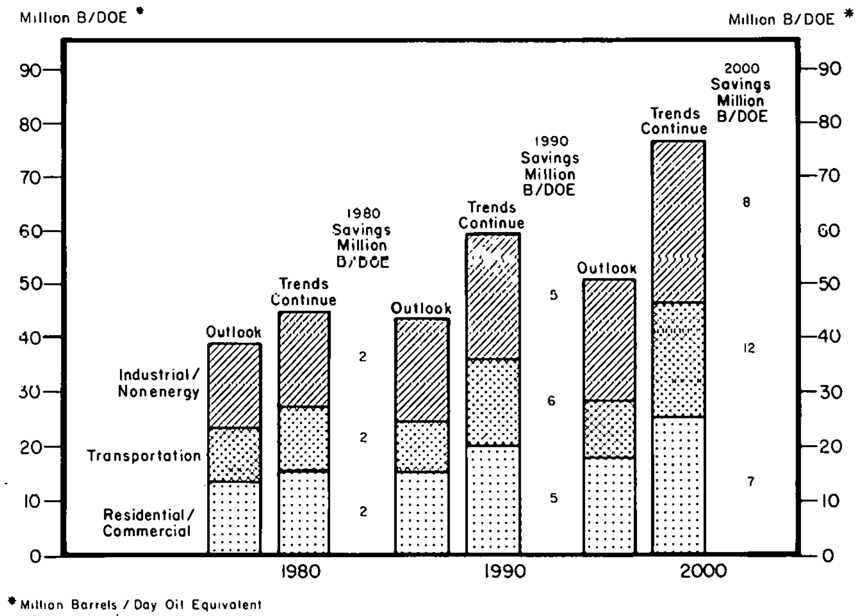

Fig. 6. **U.S. energy conservation.** Source: Exxon Co., "USA's Energy Outlook, 1980-2000" (1979).

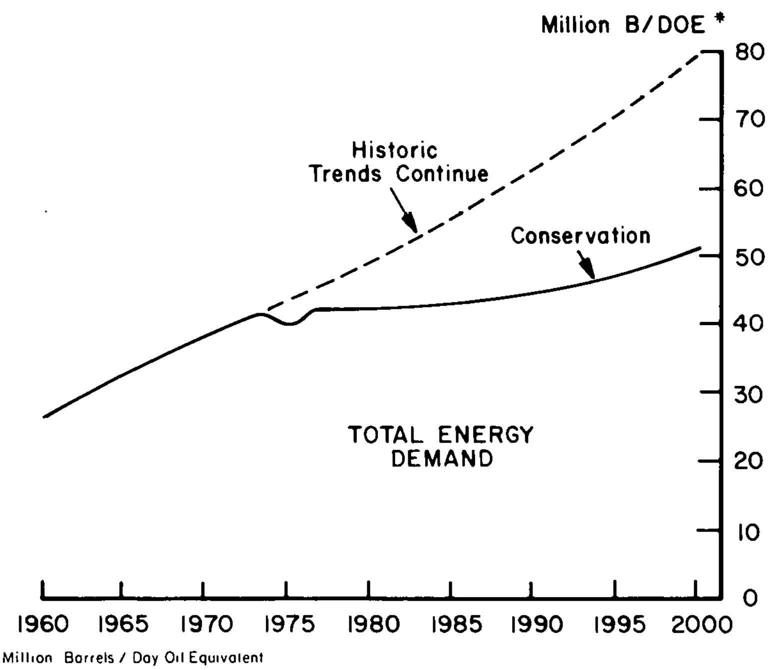

Fig. 7. U.S. energy outlook. Source: Exxon, "Synthetic Fuels."

History shows that any voluntary incentive to conserve must have a monetary base. The case of fuel conservation in Los Angeles following the Arab oil embargo is a prime example. In November 1973, the city's Department of Water and Power realized that 11 million barrels of already contracted oil would not be delivered. To forestall the substantial shortfall in electrical production, an ad hoc committee representing the civic, business, and labor constituencies of the community was formed to devise a possible solution to the problem. The result was the establishment of mandatory targets for reductions in all energy-consuming sectors of the city. It was left to the individual consumers to implement specific cuts, but the goal was to reduce overall electricity consumption by 12%. The penalty for noncompliance was a 50% surcharge on the customer's total electric bill. The voluntary response to this law was so overwhelming that the target was exceeded by 6% and the penalties never had to be applied.

Much remains to be done to stretch available oil and gas supplies. We shall see real progress in this direction as the costs of gasoline, other oil products, and natural gas are allowed to rise to levels consistent with world oil prices paid for the increment of imports required. Unfortunately, such costs are under virtual control of the OPEC cartel rather than being properly related to the real costs of finding and developing replacement resources. Within the new economic framework of the 1980s, engineers likely will find ample encouragement and incentives to apply innovative conservation technology to existing plants as well as to new facilities. In this regard, the transition period will provide many challenging opportunities for the profession.

Since even the most vigorous domestic production activities and conservation efforts will not alleviate the problem of our dependence on foreign oil, we must consider other temporary means to reduce this dependence. To help soften the blow of another possible oil cutoff, plans are under way to expand our strategic storage to a six-month supply. We are also encouraging our allies to stockpile petroleum for emergency use. The cost of storage will be high, on the order of $2 billion per year, but acceptable in view of the alternative adverse impact upon the economy and the national security.

To be prepared for the 1990s and beyond, we must immediately begin large-scale development of all our domestic energy sources, including a synthetic-fuels industry. As I previously stated, the United States holds one-third of the world's coal reserves as well as large sources of uranium. At a cost and with time, coal production from known reserves could support the total U.S. energy demand for 50 years. Additional probable reserves could extend this period approximately 300 years. The problem, of course, is in providing the liquid and gaseous hydrocarbons in the form required by end users. The technology for utilization of coal is currently available, and the thrust of the Carter administration's latest energy program is to foster substitution of domestic coal for imported oil. The incentive to take advantage of this resource, however, is not yet in place. For example, construction of coal-fired plants is now so mired in the swamp of political and environmental regulations that the lead time for a new plant is approaching the 10 to 12 years now required to construct a nuclear power plant. Also, regulations on strip mining and air emissions further complicate the use of coal.

Any prognosis of our energy future some 20 years hence is tenuous since it assumes how much we will be able to conserve, the rate of economic progress, domestic and worldwide petroleum discoveries, and the speed with which conventional and nonconventional new sources may be developed. Within this array of parameters, the actual supply-demand balance of the next decade will emerge. But we can be sure that our predictions today are not right and that they must be continually updated as progress is made toward the objective of energy self-sufficiency.

We must not allow the vast numbers of uncertainties before us to trap us into an attitude of immobility. As engineers standing at the forefront of technologies and developments to improve our energy situation, we must convince the American people of the need for a sensible and immediate energy program. For the United States to regain control of our energy future, our citizens, the politicians that represent them, and our nation's business leaders must work together to reevaluate the wisdom and the long-term effects of the energy policies being made today. Our present energy situation and our future energy goals suggest that a sound domestic policy must have as its basis these goals:

- Strict conservation of energy
- Aggressive oil and gas exploration and production
- Strong efforts to develop coal resources
- Development of nonconventional energy sources such as solar, biomass, and geothermal
- Improvements in the nuclear-regulation climate
- Development of alternative sources of conventional fuels, such as tar sands, shale oil, coal gases, and coal liquids
- Resolution of environmental and energy-development conflicts
- Storage of a six-month supply of strategic petroleum reserves

Engineers are, and always have been, the leaders in technology, not the followers. We must continue to set the pace by becoming involved in the government decision-making process, especially in the formulation of energy policies. Our influence will grow when we take the time to inform the general public on energy affairs and encourage them in turn to write their government representatives. The National Society of Professional Engineers, having this exchange of information as a prime objective, has established the NSPE Energy Awareness Fund, which provides a mechanism to develop for the public and the engineering community educational programs on the nation's energy supply and resources. It will enable the society to sponsor seminars and conferences on energy and to work with other organizations on educational programs; it will also provide a means of collecting, maintaining, and making available to the public energy-related resource material.

Engineers must present their energy views by giving speeches, publishing articles, participating in radio and television talk shows, and taking part in civic activities. To meet our clear-cut goal of reducing our dependence on foreign imports, we must make an all-out effort to develop all available domestic options as efficiently as possible. There will be no miracle nor technological fix to remove us from the shadow of OPEC. Only a concentrated and cooperative effort among our citizens, our politicians, and our businessmen can accomplish this goal, and the sooner we begin to take strides in this direction, the better.

The past is prologue to the future. We have a great challenge: to participate in shaping the energy destiny of our country.

Questions and Answers

Marty Rowland (Michigan Pro-Energy Coalition, Ferndale, Michigan): Could the Energy Awareness Foundation make a presentation to the Michigan Pro-Energy Coalition (MITEC)?

Mr. Bovay: Yes! The Awareness Committee welcomes the opportunity to meet with any recognized, well-organized, pro-energy group for presentations and dialogue that would help inform the public and government decision makers about the nation's energy needs.

Mary A. Smith (Detroit, Michigan): What educational packages are available at the grass roots level for the public, and in what way is this information distributed?

Mr. Bovay: Slide and tape presentations and various brochures, proceedings, summaries, and reprints are available[3] from The Energy Committee, NSPE, 2029 K Street, N.W., Washington, DC 20006.

Charles O. Hanson, P.E. (Detroit, Michigan): What is the status of the high-pressure gas reserves located in the Gulf states and of reserves of offshore deposits?

Mr. Bovay: A recent U.S. Geological Survey conservatively estimates available unconventional natural gas (geopressured methane) at 3 quads in Louisiana and Texas and 3 quads offshore. There is currently considerable drilling activity below the 15,000-ft level, where gas is unregulated. Estimates of recoverable reserves vary considerably, but realistically and without cost considerations, reserves appear to fall in the range of 50 to 250 quads.

Robert J. Case, P.E. (Detroit, Michigan): Zero growth is termed unacceptable; energy consumption projections curve infinitely upward. How do we reconcile these assumptions with the fact that we live in a finite world?

Mr. Bovay: As I stated in my speech "Energy: Overcoming the Limits" at the Limits to Growth '75 meeting, technology, growing exponentially, is the most logical, reasonable, and tangible hope for the future of this planet. In its broadest sense, it is a total package of mental and material tools which mankind uses to make and to do things. It is more than science and machines. It covers the whole spectrum of intellectual skills, including language and ideas.

The technological community is at work on the challenge of rational planning for the future. With support from the government, industry, and the populace, scientists and engineers will make the planning process practical, workable, feasible. In fact, technology may eliminate the finiteness of the planet Earth through expeditions to the moon, the planets, and beyond. Man, with his ever-resourceful mind, need not be limited to a finite sphere. The universe and its resources are infinite.

Stanley M. Rosenbaum (Oak Park, Michigan): A recent article in a commentary magazine asserts that the U.S. government ignored and suppressed an internal report that the United States had enough fuel reserves to handle any Iranian oil cutoff which might result from the 1979 Iranian crisis and that when the cutoff occurred, the administration adopted an official stance that there was an oil shortage caused by it, thus helping to drive up oil and gas prices for the American people. To your knowledge, how accurate is the article's claim, and if it is true, what implications may or should be drawn about the administration's energy policy?

Mr. Bovay: The claim is inaccurate. The Iranian oil cutoff did not cause price increases. They were caused by OPEC cartel action. The Mideast, including Iran, supplies about one-third of the world's oil.

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[3]For a list of the items available, see the inside of the back cover.

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James E. Funk, P.E.
Coauthor

James E. Funk serves the University of Kentucky in a threefold capacity: as associate vice-president for academic affairs, coordinator of energy research, and director of the Institute for Mining and Minerals Research, which conducts major research and development programs in coal utilization supported by the Kentucky Department of Energy, the federal government, and private industry. Since joining the University of Kentucky faculty in 1964, he has also served as associate dean and, later, as dean of the College of Engineering.

Dr. Funk serves on the **NSPE Energy Committee** and has been active in the field of energy for 25 years. His pioneering work on the thermodynamics and energetics of thermochemical production of hydrogen from water has attracted the support of General Motors, the National Aeronautics and Space Administration, Westinghouse, the Electric Power Research Institute, and the Department of Energy. A founding member of the International Association for Hydrogen Energy, he serves on the editorial board of the association's *International Journal of Hydrogen Energy*.

Dr. Funk received the degree of Chemical Engineer from the University of Cincinnati; he earned M.S. and Ph.D degrees in that field at the University of Pittsburgh. In 1973 he was named a distinguished alumnus of the University of Cincinnati College of Engineering; also that year he studied in Ecuador as a senior Fulbright-Hays scholar.

Dr. Funk also served as chairman of the Kentucky State Board of Registration for Engineers and Land Surveyors for three years.

The author of over fifty scientific papers, a guest lecturer at many foreign universities, and a frequent consultant to the government and to industry, Dr. Funk is a leading authority on coal.

How we deal with the energy situation in our country will exert a strong influence on our future well-being and the position of the United States in world affairs. It will take the best efforts of all segments of our society, especially the technical and scientific communities, to make the proper choices in light of uncertain and rapidly changing worldwide energy conditions.

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Leslie C. Gates, P.E.
Coauthor

Leslie C. Gates is chairman and chief executive officer of Gates Engineering Company. His career with the firm spans 35 years: beginning as an associate with Ferguson-Gates Engineering Company in 1946, he became a partner in 1955 and the owner in 1958; from 1961 to 1979 he served as president of the company, which took its present name in 1962.

Mr. Gates received a B.S. in civil engineering from Virginia Polytechnic Institute in 1940. During World War II he served in the U.S. Army's Combat Engineers, European Theater of Operations.

A registered professional engineer in 17 states, Mr. Gates serves on the **NSPE Energy Committee** and is a three-time past president of the West Virginia Board of Registration for Professional Engineers. He has been active in NSPE for over 30 years, serving as state president in 1951 and as national president in 1974-1975, in addition to chairing numerous national committees. His other professional memberships include the American Society of Civil Engineers, of which he is a fellow, and the American Institute of Mining, Metallurgical and Petroleum Engineers. He is also active in a number of civic and business organizations, including the West Virginia Chamber of Commerce, which he served as president in 1978-1979.

Mr. Gates' long experience in the area of coal and his numerous articles in *World Coal* and other publications indicate his authoritative knowledge of the role which coal must play in our energy future.

> *Our republic probably has never faced a more serious situation than our energy dilemma, nor has it been confronted with more dire consequences for ill-conceived and poorly executed solutions. Clearly the application of a poor solution to our energy problem can have devastating ramifications on our inflation problem.*

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The Future of Coal: 1980 and Beyond

James E. Funk, ***Associate Vice-President for Academic Affairs, Coordinator of Energy Research, and Director of the Institute for Mining and Minerals Research, the University of Kentucky***

Leslie C. Gates, ***Chairman and Chief Executive Officer, Gates Engineering Company***

Two central facts are evident concerning coal in the United States today:

1. We have a great deal of coal.
2. Coal is being utilized far below its potential.

Thirty-one percent of the world's coal reserves is in the United States (Table 1). The U.S.S.R. follows with 23%; Western Europe has 18%; and the People's Republic of China has 15%. The remaining reserves lie in other countries. It has been estimated that the United States has 250 billion tons of recoverable coal. This figure represents over 90% of the U.S. proven reserves of fossil fuels. The remainder of somewhat less than 10% is about equally divided between crude oil and natural gas. Figure 1 shows how the 250 billion tons of U.S. coal reserves are distributed.

Table 1. Estimated distribution of world coal reserves

(percentage of total)

Based on the amount of reserves in place that can be recovered under current local economic conditions using available technology (world total: 652 billion tons)

United States	31
U.S.S.R.	23
Western Europe	18
People's Republic of China	15
All others	13
World total	100

Source: *World Energy Conference Survey of Energy Resources*, 1974.

Eastern coals are generally bituminous, with a heating value of 10,000 to 13,000 Btu/lb. Bituminous coals comprise roughly one-half the total U.S. reserves. The western and southwestern U.S. coals are mainly subbituminous, with a heating value of roughly

8000 Btu/lb, and lignite, with a heating value of 6000 Btu/lb. Our 250-billion-ton coal reserve represents an enormous energy base. In terms of heating value, it is equivalent to approximately 1 trillion barrels of oil, almost 25 times larger than the U.S. reserves of crude oil and natural-gas liquids. Despite the immensity of this energy source, the most important aspect is not that there are recoverable reserves sufficient to take care of our foreseeable needs centuries into the future. Of greatest importance is that coal can provide the energy for our immediate needs during the next 40 or 50 years, thus enabling us to continue research and to develop other alternatives and bring them on-line as they become economically feasible.

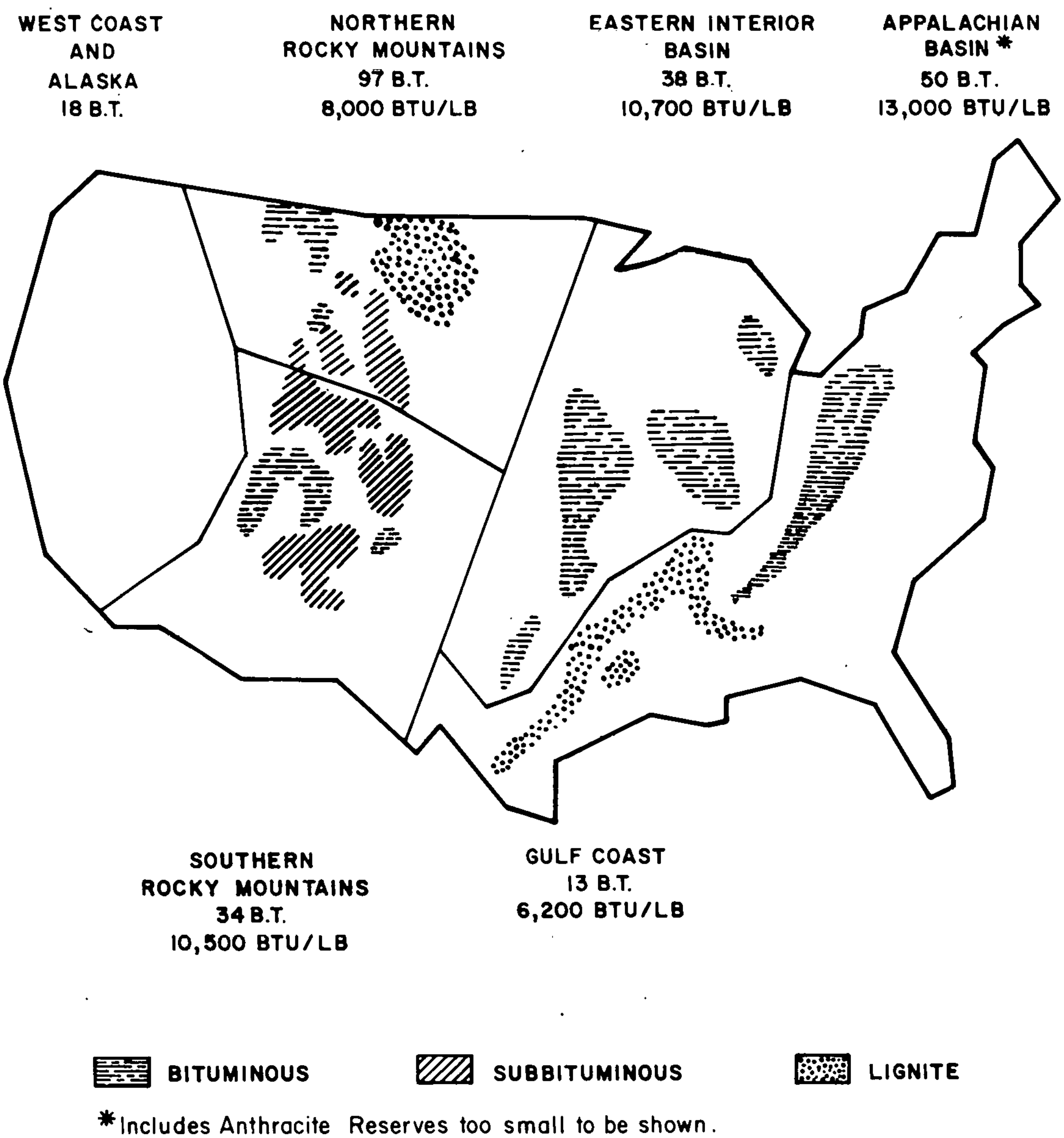

Fig. 1. Distribution of U.S. 250-billion-ton coal reserves.

The energy consumption pattern in the United States does not reflect the character of our resources. Energy consumption by source and sector for 1979 is shown in Tables 2 through 4. The numbers represent quads, or 10^{15} Btu. The important thing to notice is that 47% of our energy comes from petroleum and 26% from natural gas (Table 4). Coal provides only 19%. Clearly we are using the most of what we have least. Over 24% of the energy we used in 1979 was imported, causing a huge deficit in our balance of payments and real problems for our domestic economy. Figure 2 shows the energy demand by consuming sectors. Transportation demand is projected to diminish by the year 2000; residential and commercial consumption will increase to some extent and industrial will increase also. Figure 3 shows the source of this energy. Notice that oil use is going to decrease, natural gas consumption is going to stay about the same, and supplies of coal and nuclear power are going to increase substantially.

Table 2. U.S. energy consumption in 1979 by sector and source

In quads (10^{15} Btu)

	Coal	Natural gas	Petroleum	Hydro	Nuclear	Total
Residential and commercial		8	7			15
Industrial	4	8	8			20
Transportation			19			19
Electric power	11	4	3	3	3	24
Total	15	20	37	3	3	78

Source: Department of Energy, *Monthly Energy Review*, DOE/EIA-0035/02(80), February 1980.

Table 3. U.S. energy consumption in 1979 by end-use sector

	Quads	%
Residential and commercial	29	37
Industrial	29	37
Transportation	20	26
Total	78	100

Source; Department of Energy, *Monthly Energy Review*, DOE/EIA-0035/02(80), February 1980.

Table 4. U.S. energy consumption in 1979 by source

	Quads	%
Coal	15	19
Natural gas	20	26
Petroleum	37	47
Hydro	3	4
Nuclear	3	4
Total	78	100

Source: Department of Energy, *Monthly Energy Review*, DOE/EIA-0035/02(80), February 1980.

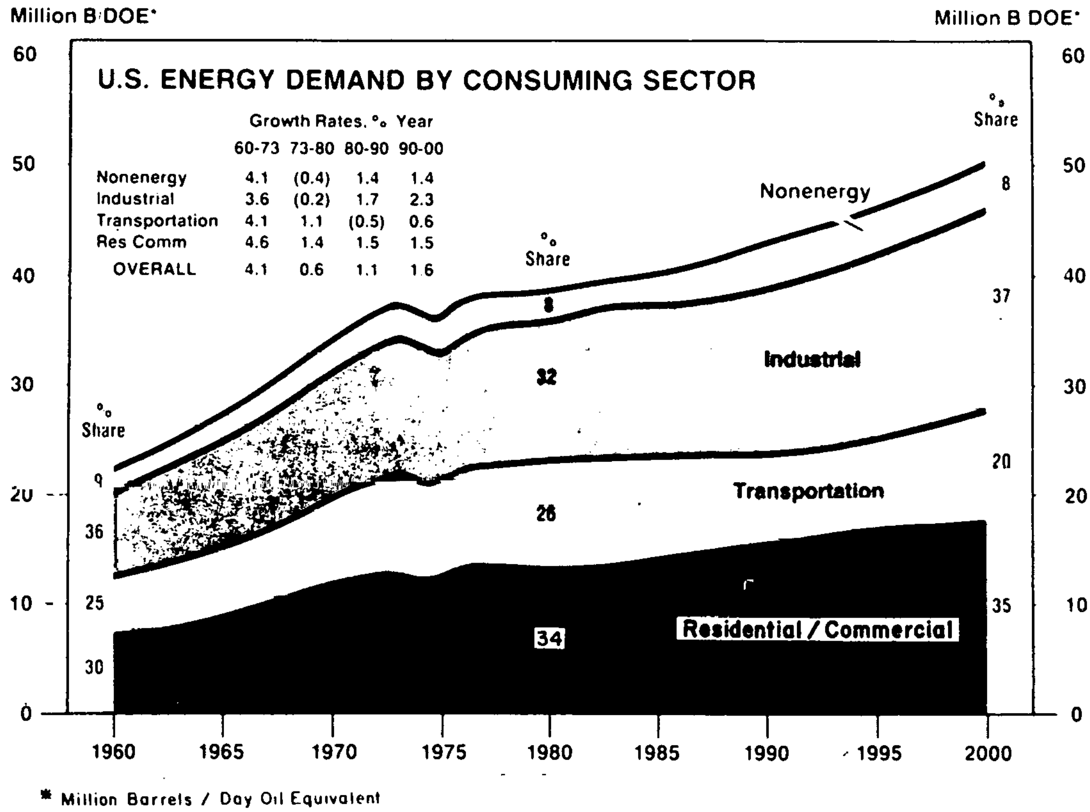

Fig. 2. U.S. energy demand by consuming sector. Source: Exxon Co., "USA's Energy Outlook, 1980-2000" (1979).

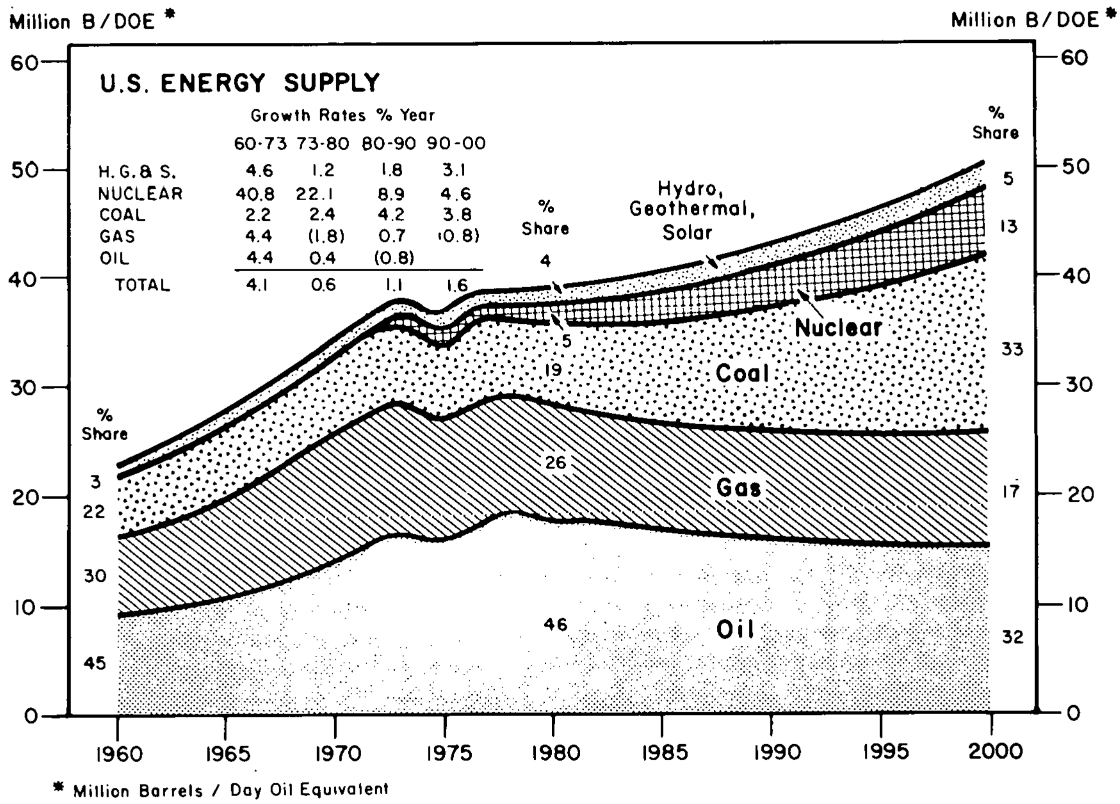

Fig. 3. U.S. energy supply. Source: Exxon Co., "USA's Energy Outlook, 1980-2000" (1979).

Our energy consumption has not always followed this pattern. There was a time when coal was the major supplier of U.S. energy needs. In the early 1920s, shortly after World War I, coal was providing over 75% of the energy used in the United States. The use of oil and natural gas expanded rapidly during the 1930s and 1940s, and by the end of World War II, oil and gas had surpassed coal as the principal source of energy for the United States (Fig.4).

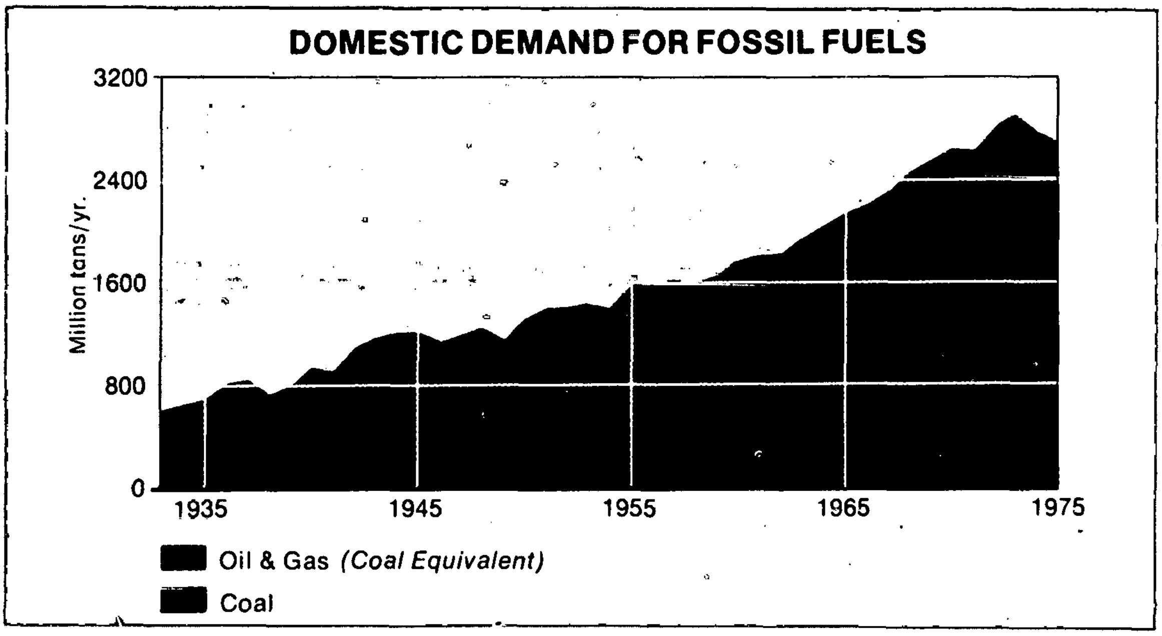

Fig. 4. Domestic demand for fossil fuels.

The dominant influence in the rapid expansion of the use of gas and oil was government policy which fixed their prices at low levels and encouraged switching to these fuels. Construction of major pipelines from the oil fields to the East Coast brought a cleaner and cheaper fuel to large metropolitan markets. The railroads, once major users of coal, switched to diesel locomotives. From the 1940s to the 1960s, John L. Lewis made the labor union a powerful force in the coal fields, and as the mines were unionized, they were also mechanized. Even so, markets for coal continued to shrink and disappear, as shown in Fig. 5. The promise of nuclear power and strong efforts by the government, through the Atomic Energy Commission, to promote nuclear power diverted our attention from coal as a major energy source. More recently the Environmental Protection Agency (EPA) required conversion of many electric generating plants from coal to oil and gas. We forgot about coal and were content to rely on oil and natural gas until nuclear power could take over. It is now clear that we cannot forget about coal. It will, in fact, play a major role in our energy picture in the next three to four decades. The situation was well summarized by Earl T. Hayes, formerly chief scientist at the U.S. Bureau of Mines, who wrote in the January 1979 issue of *Science*:

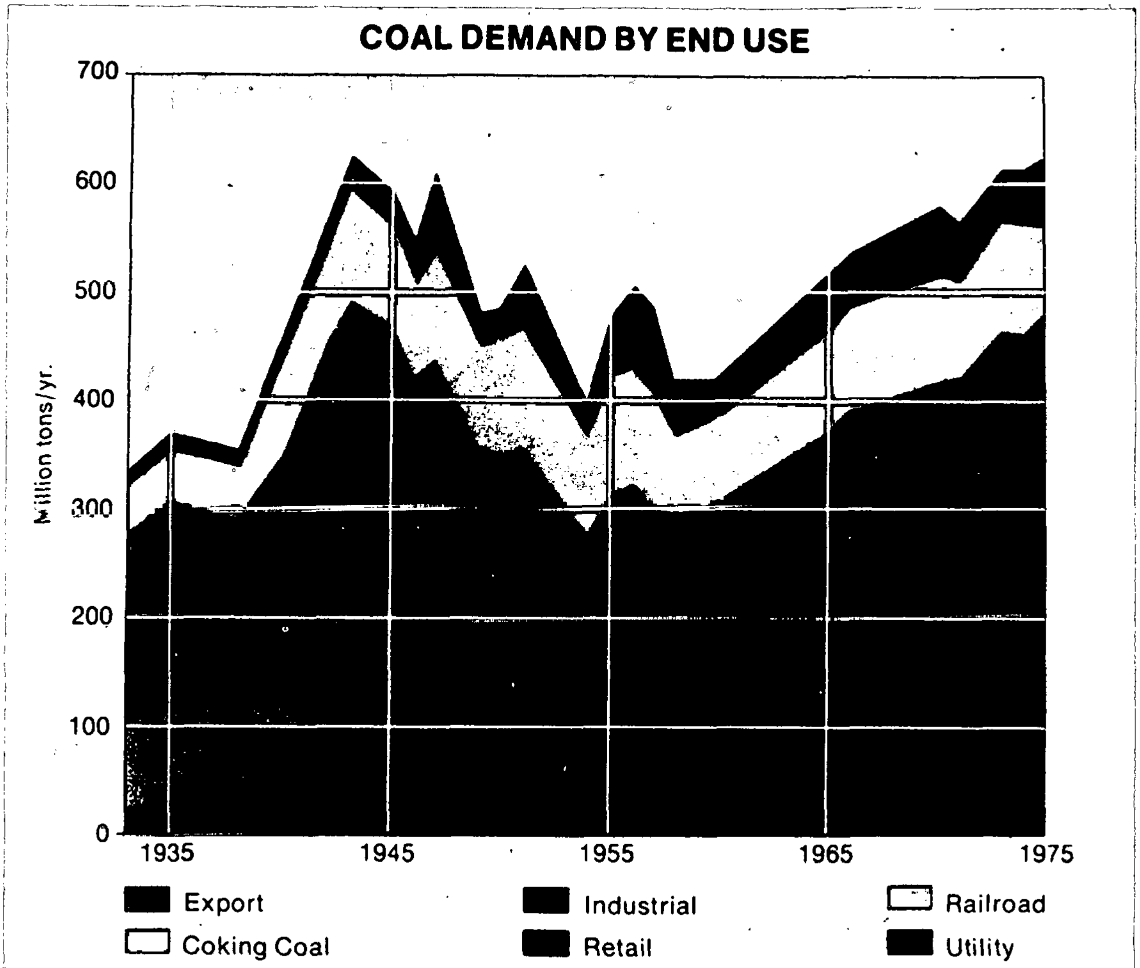

Fig. 5. Coal demand by end use.

> We have sufficient energy resources to supply our basic needs for many decades, but the costs will rise continually. The country still does not understand the problem. The layman wants to believe in inexhaustible, cheap gasoline and in this has been supported by many unsubstantiated claims. The time has come to realize that no miracle is imminent and we must make do with what we have. We will never again have as much oil or gas as we have today, nor will it be as cheap. Nuclear energy has been a major disappointment. Solar energy will be slow in developing and, contrary to popular opinion, quite expensive. Coal is the only salvation for the next few decades.

There is no shortage of predictions and projections that coal production must increase substantially in the next 10 to 20 years. In 1979, the United States produced 770 million tons of coal. Studies by various federal agencies (the National Energy Plan, Project Independence, the Department of Commerce) and technical groups [including the National Research Council Committee on Nuclear and Alternative Energy Systems (CONAES)] project coal production of 1200–1300 million tons per year by 1990 and of 1700–1900 million tons per year by 2000. Exxon recently published *USA's Energy Outlook, 1980-2000*, which calls for coal production of almost 2300 million tons per year by the year 2000 (Fig. 6). This projection has coal supplying 33% of our energy needs in 2000 and shows natural gas dropping from 26 to 17% and petroleum dropping from 46 to 33%. The compound annual growth rates for the use of coal are 4.2% from 1980 to 1990 and 3.8% from 1990 to 2000. The use of coal in traditional markets will have to be expanded if we are to realize these growth rates, and coal will have to be moved into those sectors of our energy economy that are now being served by petroleum and natural gas. As shown in Table 2, 3 quads of petroleum and 4 quads of natural gas now go to electric power generation. It is in this sector that coal can have the most immediate impact. Figure 7 shows that projected coal requirements for electric power production will greatly increase by the year 2000, along with an increase in nuclear power and a virtual phasing out of oil and gas for electric power production. Eight quads each of petroleum and natural gas go to the industrial sector, where coal can also make near-term contributions. Fifteen quads of petroleum and natural gas go to the commercial and residential sector; substitution there may have to await the commercialization of improved or newly developed coal-utilization technologies. The largest single petroleum-consuming sector, transportation, now takes 19 quads of petroleum. Coal can pick up some of this requirement when we have built substantial capacity to produce liquid fuels from coal. It must be remembered, however, that each quad of petroleum replaced in some other sector will then become available to the transportation sector.

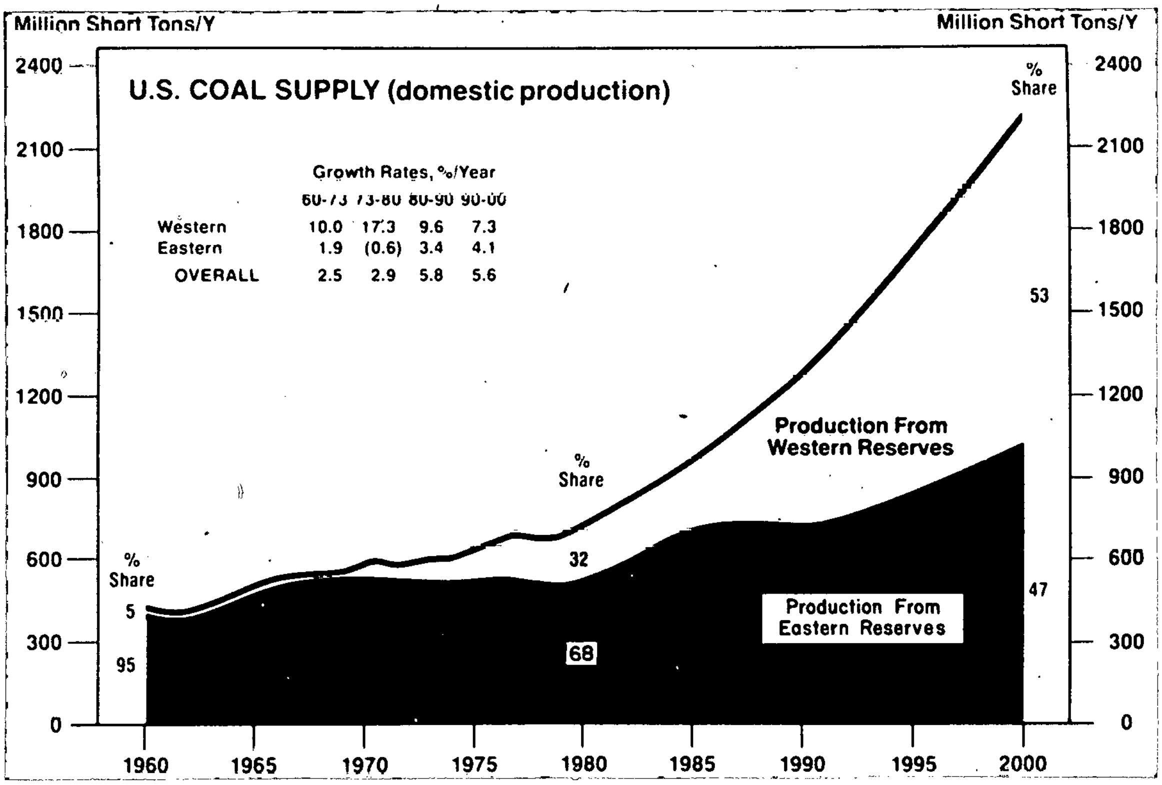

Fig. 6. U.S. coal supply (domestic production). Source: Exxon Co., "USA's Energy Outlook, 1980-2000" (1979).

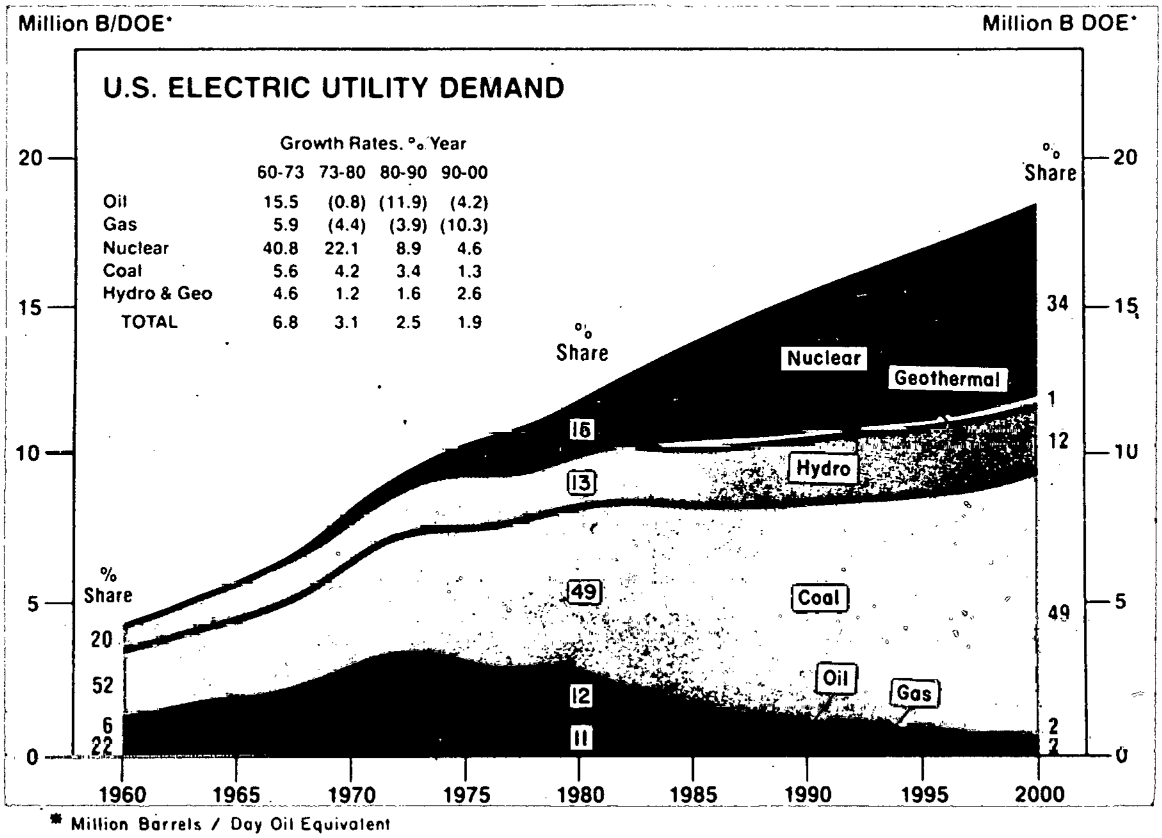

Fig. 7. U.S. electric utility demand.x3 Source: Exxon Co., "USA's Energy Outlook, 1980-2000" (1979).

The result of a broad and detailed study of the worldwide prospects for coal was recently (in early 1980) completed and published in book form under the title *Coal—Bridge to the Future.* The World Coal Study (WOCOL), as it is called, involves over 80 people from 16 major coal-using and coal-producing countries. The final report is the result of 18 months of work directed by Carroll L. Wilson of Massachusetts Institute of Technology. The major conclusions of the study are as follows:

1. Coal is capable of supplying a high proportion of our future energy needs. It now supplies more than 25% of the world's energy. Economically recoverable reserves are vast—many times those of oil and gas—and are capable of meeting increasing demands well into the future.
2. Coal will have to supply between one-half and two-thirds of the additional energy needed by the world during the next 20 years, even under the moderate energy-growth assumption of this study. To achieve this goal, world coal production will have to increase 2½-3 times, and the world trade in steam coal will have to grow 10-15 times above the 1979 levels.
3. Many individual decisions must be made along the chain from coal producer to consumer to ensure that the required amounts are available when needed. Delays at any point affect the entire chain. This fact emphasizes the need for prompt and related actions by consumers, producers, and governments and other public authorities.

4. Coal can be mined, moved, and used in most areas in ways that conform to high standards of health, safety, and environmental protection by the application of available technology and without unacceptable increases in cost. The present knowledge of possible carbon dioxide effects on climate does not justify delaying the expansion of coal use.
5. Coal is already competitive in many locations for the generation of electricity and for many industrial and other uses. It will extend further into these markets and others as oil prices rise.
6. Technology for mining, moving, and using coal is well established and is steadily improving. Technological advances in combustion, gasification, and liquefaction will greatly widen the scope for the environmentally acceptable use of coal in the 1990s and beyond.
7. The amount of captiol required to produce and transport the user facilities needed to triple the use of coal is within the realm of domestic and international capital markets, though difficulties in financing large coal projects in some developing countries may require special solutions.

The social, economic and political stability of the world in the future will depend strongly on the price and the availability of various fuels. The importance of energy to the developed industrialized countries is clear. For the underdeveloped and developing countries, an adequate supply of reasonably priced energy is a prerequisite to a rising standard of living. The United States should take a lead position not only in using energy wisely through conservation but also in using fully those forms of energy, such as coal, which we have in abundance. By such action we can make a real and solid contribution to world progress.

It is generally agreed that an expansion of coal combustion will most quickly alleviate our energy supply problems. The technologies required for such an expansion are at hand or are in late stages of development. These include flue-gas desulfurization (stack-gas scrubbing), fluidized-bed combustion, coal-and-oil mixtures, and combined-cycle electricity production using clean, coal-derived fuels. These technologies will allow for the immediate replacement of oil in the industrial and electric power sectors. Each is designed to minimize the release of sulfur oxides to the environment, and combined cycles promise a higher thermal efficiency than do conventional coal-fired plants with stack-gas scrubbers.

The development of a synfuels industry that uses coal as a feedstock will allow coal to be moved into the residential, commercial, and transportation sectors of our economy. In coal gasification, the product is a synthesis gas, mainly carbon monoxide and hydrogen. If air and steam are used as the gasifying medium, a low-Btu gas is made with a heating value of 100–130 Btu/scf. If oxygen and steam are used, a medium-Btu gas results, with a heating value of about 320 Btu/scf. Low-Btu gas can be used for process heat, space heating, or electric power production. Medium-Btu gas can be upgraded to pipeline-quality gas and can thereby substitute directly for natural gas or it can be used as a feedstock for the chemical-process industries. Technological development of coal gasification is being pursued by the Department of Energy (DOE) and a number of U.S. companies. The world leader in this technology today is Lurgi, a company headquartered in Frankfurt, West Germany. Tennessee Eastman Company will begin construction this year of plants to produce methyl acetate and acetic anhydride from coal. Eastman's process uses a gasifier being developed by Texaco and is the first large U.S. project in recent times to produce an important industrial chemical from coal rather than from petroleum-related materials.

Liquids from coal can be made by either direct or indirect liquefaction techniques. In indirect liquefaction, a synthesis gas is first made by a suitable coal-gasification process. This gas can then be converted to liquids either by a Fischer-Tropsch synthesis, such as is used in South Africa's SASOL plants, or by the production of methanol and then gasoline by the Mobil Oil Corporation catalytic process. The solvent refined coal (SRC) processes—SRC-1 and SRC-2—are designed to produce a clean solid and a clean liquid boiler fuel. Demonstration plants for the SRC processes are now being designed. A number of additional coal-liquefaction processes are in various stages of research and development by the U.S. government and by private industry. The objective is to find and develop processes which are more efficient and less costly. The largest coal-liquefaction pilot plant in the United States, which uses the H-Coal process, is operated by Ashland Oil, Inc., at its Catlettsburg refinery near Ashland, Kentucky. This $300-million project, funded by DOE, the Commonwealth of Kentucky, Ashland Oil, the Electric Power Research Institute, CONOCO, Inc., Standard Oil Company of Indiana, and Mobil Oil, is designed to process 200–650 tons of coal per day into a clean boiler fuel or a synthetic crude oil. Coal was put through the plant for the first time in May 1980, and a 90-day run is under way. Ashland Oil is now designing a commercial plant to produce 50,000 barrels of synthetic crude oil per day. The cost of such a plant is estimated to be in the neighborhood of $2 billion, and the overall plant efficiency is expected to be just under 70%. A pilot plant for the Exxon Donor Solvent process, of a size similar to that for H-Coal, is now operating at Baytown, Texas. There is no question that synfuels, already technically feasible, can provide the answer to diminishing oil and gas reserves. However, the marketplace should properly dictate the time of introduction of synfuels into the American economy. Long lead times to commercialization require a development program now so that synfuels will be ready when the price of natural fuels permits their entry into the marketplace.

The high cost of synfuels from coal is often cited as a reason to proceed slowly; however, no ceiling is in sight for the price of imported oil. It has been estimated that a 2% perceived shortage of oil may result in a 20% price increase. The steadily increasing price of oil and the virtual certainty of shortages in the future are strong indications that synfuels from coal will be economically viable when they are ready to come into the market. Due to long lead times, this will not be before 1985–1990. In a recent address to the Executives Club of Chicago, Edward Donley, Chairman of Air Products and Chemicals, Inc., said:

> To move in the direction of energy independence, we need the passage of the current legislation to provide for initial synfuels developments. For the administration and the Congress to accomplish this in a free democratic society such as ours, a majority of our citizens must understand and support the program.
>
> We have waited dangerously long. We need to go forward now and to be prepared to hold steady to a firm and resolute course for many years into the future.

We agree in general with Dr. Donley's comments. The use of the term "energy independence," however, often is overemphasized. Even though energy independence may be an ideal objective, from a practical standpoint it is much more important for our country to attain and maintain a strong, viable economic position in the world. A strong and healthy economy can make our country energy sufficient without its necessarily being energy independent.

What is preventing a more rapid expansion of coal utilization in the United States? While there is no simple answer to this question, social, political, and institutional constraints must rank high on the list. Recent laws and various regulatory agencies and procedures have us in a position from which it is very difficult to move.

Coal is the fuel for the immediate future. Paradoxically, the production of coal continues to be hampered by restrictions imposed by the federal government which could impair the use of coal as a source of energy. These restrictions need to be moderated in order to relieve our dependence on foreign oil and to assist in our achieving energy sufficiency.

To begin with, we should look at the federal agencies: DOE, EPA, the Department of Transportation, and many other agencies are pursuing their own goals and objectives and are issuing policies that often overlap and contradict each other, creating confusion for the individuals for whom these regulations and policies are issued.

Additionally, we have conflicts among state, federal, and regional agencies concerning not only environmental regulations but also the use of oil versus coal (as shown by the quick and spontaneous opposition to the proposed coal-conversion legislation that the president recently sent to Congress). This opposition came about because of acid rain and the question of how to control sulfur dioxide (SO_2) emissions.

There is sufficient data to indicate that SO_2 by itself is not as toxic as many other pollutants present in the atmosphere. However, because SO_2 is easier to detect and to measure than any of the other pollutants, it has become a central issue in the discussion of the burning of coal. This SO_2 debate has been, and will continue to be, a detriment to the burning of coal, mainly in highly populated areas. The SO_2 requirements vary depending on the age of the plant. New plants built after 1977 are permitted sulfur emission levels no higher than 1.2 lb of SO_2 per million Btu of heat input. After 1977, plants were required to install the best available technology (BAT) for removing SO_2 from stack-gas emissions. The 1979 BAT Act requires scrubbers be put on all plants regardless of the sulfur emissions of the coal and requires at least 70% efficiency in stack-gas emission scrubbers. However, higher-sulfur coal may require scrubbers that are 90% efficient.

Until EPA reexamines itself and adopts national, standard limits for SO_2 emissions which are more in accord with the factual evidence of the toxicity of SO_2 than with emotionally presented data, short-term compliance with EPA regulations will continue to deter the burning of coal, even though the public will probably not curtail its demand for electricity in the long term but will ask that the power be there when lights or television sets are switched on.

Reasonable and fair changes have to be made to the present laws and regulations to ensure not only that coal can be burned but also, at the same time, that America's quest for clean air can continue by identifying the crucial pollutants, learning how to fight them, and, through new technology, doing it in a way that will consider cost and benefits.

As stated by John D. Rockefeller IV, governor of West Virginia and chairman of the President's Commission on Coal, "Coal is cheaper, it's here, it's American, and there are a lot of people who want and need the work!"

We have coal deep in the mountains of Appalachia and in the Ohio Valley as well as in the vast strip mines in the West. However, productivity per worker in the older underground coal mines of the East has been cut by more than half since 1969, and most of this cut has been the direct result of stiffer federal health-and-safety standards and of wildcat strikes by the United Mine Workers (UMW) locals, even though such strikes are currently not a problem. Since the record 110-day strike by the UMW in 1978, wildcat strikes have declined by 90%. This new indication of togetherness and peace was disrupted by only one major walkout, a week-long action against Consolidation Coal in West Virginia. Both company officials and union leaders cautiously predict that a strike will be avoided when the UMW contract expires next year. Effective communication between union leaders and management officials is necessary if the coal industry is to convince the nation that coal can be an efficient and reliable source of energy.

The 1969 Coal Mine Health and Safety Act became law as a result of the national attention focused on coal mine fatalities. No reasonable person can fault emphasis on health and safety. It is obvious that high productivity of a working force cannot be attained without good safety practices. However, in this case, the nature of emphasis was such as to be counterproductive.

This legislation was so written as to require certain techniques and equipment not then available—it was beyond the state of the art. The impact on underground-mining productivity was sudden and devastating. The average productivity, on a tons-per-man basis, declined from a high of about 15.6 tons to about 8.5 tons. Much of the industry found itself with long-term commitments for coal deliveries at a price inadequate to ensure a reasonable return on investment.

The issue of coal mine productivity and how to improve it was well documented in a paper by John W. Straton, president of Gates Engineering Company. In his paper, "Improving Coal Mine Productivity," Mr. Straton cites as the cause of decreasing productivity not only labor unrest and stiff federal regulations but also the lack of effective planning by managers who fail to develop means to increase production. Management must look at itself and drastically change its basic philosphy if the problem of decreasing productivity is to be solved. In addition, mining-equipment manufacturers should intensify research to develop new machinery, which might employ a totally different concept of production.

Obviously, improvements in production should be made that will overcome not only the impact that the Health and Safety Act had on productivity but also the natural conditions, labor-management contracts, and workers' skills and attitudes that impede productivity.

Productivity tends to decline over a long period because coal seams being mined today are thinner and have poorer natural conditions than seams mined in the past. More efficient low-coal equipment and improved roof-control practices make it possible to mine in thinner seams and under more adverse conditions than in the past. However, the technology that allows for efficient mining of thin seams still cannot make possible the productivity of mines with thick seams.

Since 1969, a worker has had the opportunity to bid for an opening which is more attractive to him, even if pay for the available job is equal to or less than that for his current work. When the labor force is expanding to perform additional work required by the 1969 Health and Safety Act, job bidding is highly disruptive. It has been difficult to maintain a stable work force which can work in a well-coordinated manner.

Today's younger work force often uses safety regulations as a device to refuse to work if the work atmosphere is not completely suitable. It is only natural to want to work under conditions as safe as possible, but there are some workers who harp on safety for other reasons. It is often said that today's workers are not interested in doing a good job and maintaining a high level of production. This may be true in some instances. But if labor, management, and government could find a common ground on which safe production activities could proceed without frequent delays and interferences, today's workers would be as interested in productivity as were yesterday's.

Another issue with which the coal industry is confronted is land-reclamation and land-control laws and regulations. Land-reclamation requirements as stated in the 1977 federal Surface Mining Control and Reclamation Act have created confusion because some states have not yet drafted regulations to comply with the federal statute. A clear example is the case of West Virginia. In spite of its being one of the first states to legislate strong reclamation requirements, not until this past legislative term did the state law comply with the federal statute. Worse yet is the fact that the Surface Mining Control and Reclamation Act, if interpreted in a tough manner, may eliminate the stripping of up to 80% of the available coal in the West. If states adopt the broadest possible definition of what constitutes an alluvial valley, where strip mining is prohibited because it might make impossible the recovery of water resources, many of the good, thick seams of coal will remain covered.

Adding to this unfavorable situation, restrictive laws and regulations passed during the last few years have withdrawn from coal exploitation millions of acres of federally owned land in the West. To exploit this land, the operator has to file an environmental impact statement on the damage that will result to the land and must also perform detailed testing procedures. Under these conditions and because of competitive bidding, there is no incentive to develop new land.

Assuming that there were no restrictions and that coal could be plentifully produced, there is no assurance that it could be shipped or transported around the country to supply coal users. The transporation problem is one of the greatest constraints on the use of coal. Approximately 90% of the coal mined in the United States has to be transported from the mining operation to the consumer. Most of this coal is transported by rail; however, the deteriorating U.S. railroads are having trouble keeping pace with the additional demand for transportation of coal. According to a study by Pacific Power and Light Company, if all electric utilities in Oregon and Washington built nothing but coal-fired plants to meet the growth in energy demand, by the turn of the century, freight trains a mile long would have to travel through those states every 60 seconds, day and night.

New railroad deregulation has given incentives to rail companies to expand and to improve their operations. The capacity of the transportation system must be improved to handle an increase in coal traffic from the present 405 million tons per year to 675 million tons per year in 1985. The railroad industry will have to lay track to new operations in the West. Many miles of roadbed must be strengthened to take the heavier traffic. Some 8000 locomotives and about 150,000 gondola and hopper cars must be added to the new railroad fleet. The railroad industry cannot perform miracles overnight. The demand for new rail, improved rail, and rolling stock is so tremendous that in order to transport the coal to different places throughout the nation without hampering the transportation of other freight, the railroad industry would have to expend between $10 billion and $15 billion between the beginning of 1980 and the end of 1985.

Slurry pipelines, through which crushed coal and water can be pumped thousands of miles, are an efficient means of coal transportation. However, slurry pipelines are being opposed by railroads and farmers. Railroads oppose slurry pipelines because of the possiblity of increased competition and thus have blocked construction by refusing to grant right-of-way easements across their tracks. Farmers fear that the water to be used for the transportation of the coal will not leave enough water for their livestock and for irrigating their crops.

Some 60 new rail-barge lines will have to be built in the East and 70 more in the West. New river transfer terminals, tow boats, and barges must be added to the transport network.

In a number of areas, local highway systems must be upgraded to handle the truck traffic carrying coal to rail and barge loading sites.

In spite of the environmental constraints, stiff safety standards, transportation problems, and declining production, the U.S. coal industry can still reach a 1-billion-ton production, which is ½ billion tons less than previously projected by 1985, if the administration and the American people signal that they will not allow bureaucrats to draft strip-mining or clean-air regulations so restrictive as to impede the goals of the National Energy Plan. If there are signals that there will not be future restrictions, the utilities, railroads, and industry will be given an incentive to raise and invest the large sums of money necessary to convert to coal as a major energy source. As stated in *Interim Report of the President's Commission on Coal:* "... federal energy and related policies must be molded to a clear, bold plan of action. The commission concluded that the primary obstacle to greater coal use is the lack of a strong consistent federal coal policy and the framework of certainty such a policy would provide."

The commission urged the establishment of a procedure to identify and resolve regional, state, and local conflicts and to reconcile conflicting interest within the federal government to enable the nation to aggressively pursue a program of oil import reduction through increased reliance on domestic coal.

In some ways, the expanded use of coal may seem to be looking to the past. I suggest that the current situation, however, calls for action which will allow us to use energy resources over which we have control and of which we can influence the price and the end use. Coal and nuclear power are the only two energy sources we have that fit the bill. I believe that we are, in fact, going to see substantially increased use of coal for various end uses in the future, and I know that the engineering profession will play a very large role in accomplishing such an expanded use of coal. It is time to stop talking about coal as the fuel of the future; we must start mining it and burning it *now.*

Questions and Answers

Neil Norman, P.E. (President, California Society of Professional Engineers): Will coal-fired electric generation plants be cost competitive in air-quality basins such as southern California?

Dr. Funk: The technology exists to operate coal-fired electric power plants with very low emissions. This technology includes combined-cycle plants utilizing gas turbines and steam turbines and high-efficiency scrubbers. Whether these plants will be cost competitive depends on the future costs of residual oil and of clean liquid fuels now available in the marketplace. I believe costs for these fuels will continue to rise, with temporary slowdowns from time to time. Therefore, I believe that coal-fired plants will be cost competitive in places such as southern California.

H. A. Niedhammer, P.E. (Livingston, New Jersey): What is the present status of transporting coal via slurry lines?

Dr. Funk: Coal slurry pipelines are being studied for many applications in both the eastern and western United States. A coal slurry pipeline has been operating in the West for some time. There is a question of right-of-way, that is, whether or not coal slurry pipelines will be allowed to use or to cross railroad right-of-ways. This question is now in Congress. It is not clear whether coal slurry pipelines will eventually win out over rail or truck or barge transportation, but it seems likely that they do have a role to play in the coal transportation systems of the future.

Gordon L. Burr, P.E. (Teletype Corporation, Little Rock, Arkansas): How energy efficient are coal gasification and liquefaction; that is, what percentage of available energy is expended in the conversion process?

Dr. Funk: The efficiency of coal liquefaction plants, from coal in to liquid products out, is around 70%. For gasification systems, depending on how things are counted, the efficiencies are somewhat higher and may range from 75 to 85%.

Question from the audience: Last year, a number of us worked at the Tennessee Valley Authority (TVA) Muscle Shoals power plant, and we saw there an extraordinarily clean operation. Could you tell us whether the removal of SO_2 at that plant is about the level we should have, or is that a case in which it's too good?

Dr. Funk: I don't know what we should have as far as SO_2 removal is concerned. It is my opinion that it doesn't make a whole lot of sense to require the same amount of sulfur removal by every plant or at every location in the United States, any more than it makes much sense to me to require catalytic converters on every automobile in all parts of the United States. I think that the question on the health effects of SO_2 is an open one at this time. There's a lot of work being done on SO_2; for example, the National Coal Association is going to fund a major study for power plants on acid rain resulting from SO_2. I'm afraid I can't answer your question specifically; I don't know what the right amount is, but I do believe that it doesn't make sense to take out all the SO_2.

Question from the audience: What about carbon dioxide (CO_2) as a pollutant? It seems to be a serious problem.

Dr. Funk: I think that one of the most serious questions concerning the use of carbonaceous energy sources has to do with CO_2: the so-called greenhouse effect, which is the increase in the temperature of the earth's surface as a result of the insulating effect of CO_2. There are a number of points to be made here. First, the amount of CO_2 in the atmosphere has been going up for the past 10 to 20 years. The temperature of the earth, on the average, has been dropping. Second, the question of carbon balance is an open one. There's a great deal of work being done in Oak Ridge, at the Institute of Energy Analysis, on the CO_2 question. Maybe a more important consideration than the use of carbonaceous sources concerns largescale deforestation: every time you take a leaf away, the atmosphere can handle a little less CO_2. The effect of CO_2 is a serious question, there's no doubt about it.

Marty Rowland, (Michigan Pro-Energy Coalition, Ferndale, Michigan): Will magnetohydrodynamics (MHD) technology be used to reduce pollution associated with power production from coal?

Dr. Funk: The very high temperatures required by MHD make it a difficult technology. It is not clear that MHD will be commercialized before the end of this century. There is no reason to believe that pollution problems associated with power production from coal would be less severe with MHD than with combined-cycle power plants in which a clean gas is produced and burned.

William J. Kilcullen, P.E. (AiResearch Manufacturing Company, Tempe, Arizona): What is your opinion of the American Indian's (particularly the Navajos idea of setting up an energy consortium similar to the Organization of Petroleum Exporting Countries (OPEC) within the United States?

Dr. Funk: There are real problems with the idea of American Indians setting up an energy consortium similar to OPEC in the United States. I think it is a fundamentally unworkable scheme. American Indians, of course, have not been very well treated, and we should seek ways to ensure that they share fully and equitably in the wealth derived from their mineral resources.

L. A. Swan, P.E. (Laguna Hills, California): With the greatest amount of low-sulfur fuel located in the Western mountain states, is the added cost of transportation to points of use offset by the cost of reducing the SO_2 from high-sulfur fuels?

Dr. Funk: The requirement that scrubbing be employed on all coal-fired power plants has tended to reduce the cost advantage of western coals over eastern coals. It is my impression that it is cheaper to burn high-sulfur eastern coals in the eastern United States in conjunction with scrubbers than to ship coal from the West.

Phil Owens, P.E. (Sandia National Laboratories, Albuquerque, New Mexico): Regarding the transportation of coal, do you foresee an increase in the use of coal slurry pipelines?

Dr. Funk: If the United States increases its coal utilization substantially, we will have a very serious transportation problem. For this reason I do foresee an increase in the use of coal slurry pipelines, especially where the water problems can be handled. There are also proposals to slurry coal with coal-produced liquids, such as methanol, and to use both the coal and the methanol at the end point.

Norm Schaffer, P.E. (N. G. Schaffer Engineering, Emmaus, Pennsylvania): I understand that coal can now be gasified underground. What environmental impact results from this?

Dr. Funk: Underground coal gasification is in the early stages of development. It has been attempted more than once in the past, and substantial operating problems have been encountered. I am not aware of any adverse environmental impacts of underground coal gasification.

Mr. Schaffer: Do you see a possible problem with underground water pollution?

Dr. Funk: Well, I think that anytime that sort of operation is done below aquifers, there's going to be a problem. I think that it's going to have to be done above major aquifers. I also believe there are going to be other, cost-related problems associated with in situ gasification, however.

R. Thomas Hobbs, P.E. (Western Electric Co., Inc., Burlington, North Carolina): How many people have been killed or have died from illness resulting from the mining environment in the coal industry from 1960 to 1980?

Dr. Funk: I don't know. It is well known, however, that coal mining can be dangerous. There is little doubt that we must do everything possible to make the mining environment safer. Increased productivity will surely depend on safer operating conditions.

Question from the audience: In terms of prompting deregulation, what impact, if any, has the National Coal Association had through its National Coal Conference and other meetings and workshops?

Dr. Funk: It's hard for anybody to have an impact when agencies in the executive branch set the regulations. It's very difficult to influence those folks, and while I don't have a lot of firsthand knowledge about this matter, it's my impression that the National Coal Association has had both successes and failures in this area.

Question from the audience: You mentioned the need for EPA standards on particulate matter to be more realistic. I'm reminded of the National Academy of Sciences' National Research Council study on EPA's margins. The EPA has had problems with standardization, and certain emission procedures have not really had conclusive evidence either warranting them or showing them to be unwarranted. In view of this fact, how do you determine that a certain parts-per-million level would be reasonable?

Dr. Funk: Well, I don't think that there is any way to know, under the circumstances you described, that a specific SO_2 concentration from the stack will be acceptable. On the other hand, I don't believe that, as a result, you should necessarily conclude that the course of wisdom is to require zero emissions. Currently, though, that is the path we're on.

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Lynn E. Weaver, P.E

Lynn E. Weaver is director of the School of Nuclear Engineering at Georgia Institute of Technology. Under his direction, enrollment in the School of Engineering has quadrupled, the number of faculty has tripled, and the annual volume of sponsored research has grown tenfold. The school issues the Georgia Institute of Technology Series in Nuclear Engineering, of which four volumes have appeared.

After earning a B. S. in electrical engineering from the University of Missouri, Dr. Weaver served two years in the Air Force supervising the installation of early warning radar. Subsequently, he worked for several years in industry on the analysis of guidance and control systems for aerospace vehicles, the design of analog computers, and the kinetics and control studies of nuclear reactors. He then obtained his M. S. from Southern Methodist University and his Ph.D. from Purdue University.

Prior to taking his current position in 1972, Dr. Weaver served as director of the Office for Environmental Studies at Argonne Universities Association. Previous posts include appointments as associate dean of engineering at the University of Oklahoma and, earlier, as head of the University of Arizona Nuclear Engineering Department.

In addition to his academic activities, Dr. Weaver serves as a consultant to a number of industrial and government organizations: recently he served on the National Aeronautics and Space Administration Advisory Committee for Space Power and Propulsion; he advised the Organization of American States on the establishment of centers of excellence in nuclear education and research in Latin American. Also, he is an executive editor for the journal *Annals of Nuclear Energy.* The author of nearly 50 reports and major publications, Dr. Weaver is one of the world's foremost authorities on nuclear energy.

> *Energy is the life and blood of our society. Every effort must be made to conserve energy and develop our resources. We have the technology and the resources to produce it. We must implement an aggressive energy policy to achieve energy independence. If this challenge is not met, our way of life and freedom of choice will be severely impacted. It would be tragic if the United States went to war over five-and-a-half million barrels of oil per day from the Persian Gulf.*

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Future Prospects for Nuclear Energy

Lynn E. Weaver, P.E., ***Director of the School of Nuclear Engineering, Georgia Institute of Technology***, Atlanta

Meeting the United States' future needs for energy in a manner that will ensure economic prosperity and domestic security presents a formidable challenge. If this challenge is not met, our way of life and freedom of choice will be severely impacted. This nation is not running out of energy resources. There is no need to lower the rate of energy growth to a level that would significantly jeopardize economic well-being. If a realistic energy policy is aggressively developed and implemented, a reasonable growth in energy use can be achieved at acceptable costs. The pattern in which we currently use our energy resources is totally inappropriate when compared to the respective quantitites of them. My talk will focus on this point and on the role nuclear energy must play in the future energy-resource mix.

At the present time, nuclear energy contributes about 12% of the nation's electric supply, or about 3.5% of the total energy budget, which does not seem very impressive. Those opposing nuclear power often say that it can easily be phased out since it represents such a small percentage. Regional contributions, however, *are* impressive. For example, nuclear power provides 30% of the electricity in Wisconsin, Maryland, Arkansas, and South Carolina; 50% in Nebraska and Connecticut; 65% in Maine; and 79% in Vermont.

Further, from an economic standpoint, in 1978 the total cost of electricity produced in the United States was 1.5¢ per kilowatt-hour for nuclear power, 2.3¢ per kilowatt-hour for coal, and about 4¢ per kilowatt-hour for oil. To have produced this energy by the use of oil instead of uranium would have added 470 million barrels of oil to our imports, at an additional foreign exchange of about $6 billion.

What role should nuclear energy play in meeting the future energy needs of this nation? To address this question properly, it is first necessary to project the future energy demand. A convenient measure of energy is the quad, which is the energy content of 7.5 billion gallons of gasoline. This is enough gasoline to run 10 million automobiles for one year. It is equivalent to 46 million tons of coal, that is, enough to fill a string of coal cars reaching from New York to Alaska. It is enough energy to supply all of the energy needs of a city of a million people for three years. The United States' annual energy use has risen rapidly, from 10 quads in 1900 to approximately 78 quads this past year. The main source of this energy changed from wood in the latter part of the nineteenth century to coal and then to oil and natural gas; it took about 30 to 40 years for each new energy source to have a major impact on the energy budget. At present, about 72% of our energy is derived from oil and natural gas, 20% from coal, 3.5%

from nuclear, 3.5% from hydropower, and 1% from other sources (biomass, geothermal, etc.).

In projecting future energy supply and demand, an annual energy consumption in the area of 100 quads in the year 2000 would seem appropriate. The year 2000 was chosen because a number of scenarios target on that date. This particular projection represents the most recent and conservative of all studies available. It takes into account population growth and the need to raise the standard of living of a large segment of our population, and it is based on a major effort to conserve energy. Even though the birthrate—1.76 live births per childbearing female—is currently below replacement, the population will not level off until after the year 2000, and there are indications that this birthrate is beginning to climb.

Assuming energy demand can be held at 100 quads, where will the additional 22 quads of energy come from? It has been well established that the United States cannot provide enough oil and natural gas to meet its present needs, much less any increases. Consequently, imports must make up the difference, which is approximately 45% at present. The increases in the price of foreign oil and natural gas are having a profound effect on the economy. Clearly, as world demand for oil and natural gas increases, the price of imports will climb. At the current rate of consumption, the United States' supply of oil and natural gas will be depleted in 30 to 50 years, even with Alaska's potential contribution. Within one generation a large fraction of these resources, which took millions of years to produce, will be gone. Further, it is estimated that the world production of oil and natural gas will peak around the turn of the century and decline thereafter. Unlike uranium, which is used only in generating electricity, these resources have many other uses, such as serving as the raw materials for fertilizers, synthetics, and medicines.

Fortunately, the United States has an ample supply of coal, which will play a major role in meeting future energy needs. It is estimated that coal could provide all our energy needs, at the current rate of consumption, for 200 to 300 years. However, there are financial, manpower, and environmental constraints that will limit the rate at which the use of coal can be increased.

The potential for a sizable increase in hydropower does not exist. At best, an additional two quads can be expected from this energy source—if environmentalists will allow more dams to be built. The present contribution of solar energy—which includes direct solar heating, tidal power, ocean thermal gradient, and wind power—toward meeting our energy needs is essentially zero. Therefore, it is unlikely that this energy source will contribute more than five quads per year, or 5% of our energy needs, by the year 2000. If we are to build a large-scale solar industry which can produce systems that are proven reliable and economically viable, it will take time and a sizable financial investment. As I mentioned previously, it takes 30 to 40 years for a new energy source to make a major contribution to the energy supply.

Nuclear power can play a major role in meeting future energy demands. The industry is in place and is capable of a substantial increase in production. There is concern that if a firm commitment is not made to the nuclear option in the near future, this capability will disappear. As in the case of fossil fuels, there is a finite amount of uranium. Best estimates are that about 20 quads of energy per year, or 20% of our energy requirements, can be obtained from uranium by the year 2000. If breeder reactors are developed and put on-line, it will be possible to expand and continue use of this energy source for several thousand years. Realistically, I believe it is possible to construct enough nuclear power plants to provide 15 quads of energy per year by the year 2000.

I mentioned that if we had the breeder reactor, we could extend our supply of nuclear fuel for several thousand years. It is a policy of the current administration to defer reprocessing, which is necessary for breeder reactors, and to defer construction of a demonstration plant that was being designed for the Clinch River project in Tennessee. That policy of deferral is based on the administration's position that we can expect to find about 3.6 million short tons of uranium in the United States. Now, recent studies by the National Academy of Sciences indicate that there is a 67% probability of finding 1.8 million short tons of uranium at an acceptable cost[1]. The probability of doubling that amount to the administration's projection is about 3%. So it seems to me that we should take the prudent course and move ahead with the development of breeder reactors and reprocessing.

It is obvious that coal and nuclear power are the only energy resources available *in this century* that can make *major* contributions toward meeting the projected energy need of 100 quads in the year 2000. Neither alone can meet the increased demand. To rely solely on coal would require 600 to 800 new coal mines; an unprecedented expansion of our national transportation system; hundreds of thousands of new railroad cars, locomotives, and barges; and new and improved right-of-ways, waterways, and coal slurry pipelines. Considering the financial investment and manpower required, it is unlikely that this growth will happen in the near future.

Coal and nuclear power together can buy the time necessary for the development and industrialization of other energy sources, such as nuclear fusion and solar. The consequences of not meeting our energy needs are serious. One has only to look at the natural gas shortage in the winter of 1976-1977 to see the impact. During that winter, the energy budget fell only a fraction of a quad short; however, in certain parts of the country, schools closed, industries shut down, and people suffered and died. Over 1200 deaths have been attributed to the heat wave this summer. I shudder to think of the additional suffering and deaths that would have occurred as a result of brownouts or blackouts.

From a technical and economic standpoint, nuclear power has been successful. Despite the accident at Three Mile Island, the safety record of nuclear power is outstanding compared with that of other sources of electric power. The risks of nuclear energy, including the risks of the complete fuel cycle, must be put into proper perspective by comparing them to those of other energy sources. Recent studies performed by the American Medical Association Council on Scientific Affairs, the Health and Safety Commission of Great Britain, and the Atomic Energy Control Board of Canada compared risks associated with energy from conventional and from nonconventional sources.[2] In each case, nuclear power proved to have comparable or less public risk. The risk to our economic and social system in *not* having nuclear power far outweighs the risk to the biosphere in using nuclear energy.

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[1]In collaboration with the National Research Council, Committee on Nuclear and Alternative Energy Systems, *Energy in Transition, 1985-2010* (1980).

[2]American Medical Association Council on Scientific Affairs, "Health Evaluation of Energy-Generating Sources," *J. Am. Med. Assoc.* **240**(20), 2193 (1978); Hubert Inhaber, *Risk of Energy Production,* Atomic Energy Control Board of Canada, Ottawa, Ontario, AECB-1119 (Rev. 1), 1978.

Even with the generally favorable performance of nuclear power plants, the nuclear option has been embroiled in an intense political controversy that has drastically reduced commitments to nuclear energy. In 1974 utilities were committed to 239 nuclear power plants. That commitment has been reduced to 182 in 1980. Some of this reduction is due to a slower growth in the demand for electricity than was originally projected. However, a sizable fraction appears to be due to the following political and institutional constraints and public concerns.

- A perceived lack of government support of the nuclear option.
- Continued difficulties with the siting and licensing of nuclear power plants, resulting in extended schedule delays, increased costs, and licensing uncertainties.
- Concern over the adequacy of long-term uranium supplies due to the deferral of fuel reprocessing and of construction of a breeder-reactor demonstration plant. I mentioned previously that the known reserves most probably amount to about 1.8 million short tons, which by the year 2000 will probably fuel about 350 1000-megawatt reactors for their lifetime (30 years each). Without reprocessing and the breeder reactor, the nuclear option is dead, because the uranium supply won't be there. So we must move ahead with the breeder reactor and reprocessing.
- The public's rising concern over nuclear waste and the government's lack of commitment to demonstrate the technology and to proceed with the design and construction of waste repositories.
- Uncertainty regarding public acceptance of the nuclear option and regarding changes in regulatory requirements as a result of the accident at Three Mile Island.

If nuclear energy is to play a major role in our energy future, as I believe it must, the political and institutional barriers just mentioned must be overcome and the public's concerns must be put to rest through factual information and demonstrated technical fixes. This can be accomplished only by an aggressive national energy policy that puts into proper perspective the various energy sources, both conventional and nonconventional, and the roles which they can reasonably be expected to play in the near and intermediate future.

It would be tragic if the United States went to war over 5½ million barrels of oil per day from the Persian Gulf, especially when we have the technology and the resources to produce domestically the equivalent energy by using resources such as coal, uranium, breeder reactors, gasohol, synthetic fuels, and, in the long term, fusion and solar energy. The cost of developing and bringing into production this technology would be much less than the cost of war and would, in the long run, tend to keep down the prices of fossil fuels.

In conclusion, let me stress that energy is the lifeblood of our society. Every effort must be made to conserve it and to develop all possible resource options in a manner and time frame consistent with their expected returns, because building an energy future on an as-yet-unproven technology would be a grave mistake.

Questions and Answers

Carl Roman (Allentown, Pennsylvania): How does the United States compare with foreign countries in nuclear technology development, and what are some consequences of this comparison?

Dr. Weaver: Nuclear power in Europe, Japan, and the Soviet Union is moving ahead very rapidly, particularly in Japan, where they import about 95% of their energy and don't have the abundance that we have of coal and other sources. Consequently, they are pushing ahead very rapidly to develop nuclear power, and the breeder-reactor system. Of course, the French have made a very serious commitment to nuclear power. They have constructed a demonstration plant and have successfully operated a breeder reactor, the Phoenix reactor. They're building a super Phoenix system at the present time, a 1200-megawatt system. The Russians have completed a 600-megawatt system, which is in operation. The French, Germans, and Italians are cooperating on a breeder system. The French are reprocessing, and they are taking care of their waste, solidifying it and demonstrating waste disposal. These countries have no choice; they don't have the abundant coal reserves we have, so they're forced to move ahead. Of course, President Carter's position, because of his concern over nuclear proliferation, has been that if we did not reprocess, neither would the rest of the world. But that's not been the case; since they can't afford that luxury. So we are far behind in that area. We may have to buy our breeder-reactor technology from France.

Bill Kilcullen, P.E. (AiResearch Manufacturing Company, Tempe, Arizona): First, I'd like to compliment you on your very intelligent statement about the folly of going to war over 5½ million barrels of oil. We have the capability in the United States to supply our energy needs. Second, I'd like to ask you your opinion, as a nuclear expert, on the possibility of our obtaining a thermonuclear system that would be usable before the year 2000.

Dr. Weaver: It's impossible. To bring any new technology on-line requires three steps: scientific feasibility, engineering feasibility, and economic feasibility. They must be demonstrated before a utility will buy the system. So far, not even the scientific feasibility of fusion reactors has been proven. The experiment to demonstrate that feasibility is scheduled for 1983 at Princeton University. There are some very good experimental results that have proven the physics. Once you know the physics, you can project what's going to happen when you take the next step. Now that the physics is in hand, researchers are confident that they understand the process. The next step, of course, is to build a plant for demonstrating the scientific feasibility, and they feel confident that when they turn the machine on, it's going to work. From there you progress to a demonstration plant to prove the engineering technology, and that takes quite a long time. The economic feasibility comes even later, so it will be 20 or 30 years before you'll see a feasible system. Then there'll be a market-penetration problem; you just don't dump a thousand fusion reactors on the line overnight. Fission power, was proven economically viable in the early 1960s, today, almost 18 years later, nuclear power provides only about 3.5% of the energy budget. It takes time to develop the industry, to make the market penetration, to put the plants on the line; you can't do it overnight.

Ben O'Callahan (Georgia): What can we engineers do to overcome the hysteria that's been instilled in the public by people like Jane Fonda, who know nothing about nuclear power but tell everybody it's dangerous? As you and many others have stated, it is actually very safe. It is the lack of public, governmental, and presidential support, I think, that has caused the problem. What can we do to help solve it?

Dr. Weaver: You have to inform the public of the truth. When Jane Fonda was going around the country, a truth team followed her around, refuting on radio and television things she would say. That must have had a highly severe impact on her campaign, because she has really quieted down. I think that's an instance of trying to make the truth known. There are programs being developed by NSPE that will help inform people, but more is needed: you have to get involved; you have to get engineers involved in public debate, civic clubs, and so forth to bring the message to the grass-roots level. This is very important. NSPE is taking some leadership in this area, and we hope that it will have a major impact. Engineers by nature are introverts, and tend not to get involved in political debate; they follow a methodological pattern and shy away from political controversy. It's a tough problem because it involves a high technology. The industry is under an emotional cloud because of the public's fear of radiation. There is too much fear. We have to have a good educational program, and we have to be candid with the public. As Mr. Randall said, you can't shy away from the issue; you need to face it head-on. It's important, really that we get out and get involved.

Harry Bovay (Chairman, NSPE Energy Committee): In regard to that question, I think our NSPE Energy Awareness Luncheon ought to call our support to the NSPE Energy Awareness Foundation. That foundation is the way, I think, to finance this effort to inform the public.

Dr. Robert A. Woodson, P.E. (Woodson Consulting Engineers, St. Paul, Minnesota): Dr. Weaver, how do we combat the public's fear of terrorist actions if we use breeder reactors?

Dr. Weaver: In regard to the terrorist issue, I'm not sure that if I were a terrorist I would actually try to construct a nuclear explosive device. There are other ways of having much greater impact on the public; for example, they could poison the water system very easily. The technology required to build a weapon is not that simple, even though you may have read about a physics student, I believe at one of the Ivy League schools, who wrote a paper that claimed he could construct one. The difficulty has been far oversimplified. I think we have sufficient safeguards to make sure that plutonium does not get in the hands of terrorists, and I think that those safeguards will remain effective. The existing administration is more concerned about proliferation of nuclear weapons, especially among third-world nations, than about terrorist activities. The terrorist matter is one we certainly can handle, because there are many things terrorists can do besides trying to exploit a nuclear device.

Question from the audience: India has built a nuclear explosive device. By selling them reactor fuel, didn't we give them the capability to experiment with weapons?

Dr. Weaver: If I were to try to build a nuclear device, I wouldn't go to a power reactor; you can build a weapon from research reactors as India did. The nuclear power industry did not give India the capability of a nuclear weapon. Any country that's willing to put the necessary money into it can make a nuclear weapon. We don't have a monopoly on the technology; it's there, and any country that is determined to do it can.

Dr. Woodson: Is disposal of the waste from the breeder reactor a problem?

Dr. Weaver: The administration's current policy is to defer reprocessing and to build storage pools for reactors' spent fuel. In other words, we refuel a reactor core (1/3 of the core) every year. The spent fuel elements, which are thermally and radioactively hot, are placed in the storage pool at the reactor site. Since reactor sites are becoming constipated, the wastes will have to be moved elsewhere. So the policy is to design a construction away from reactor storage that will allow these fuel elements to be stored until the decision is made on what to do with them. Some people would permanently dispose of the spent fuel in salt mines. That would be a terrible mistake, because it would mean throwing away the energy content of the plutonium and uranium in that spent fuel. So if you reprocess you simplify waste disposal as far as the nuclear fuel cycle is concerned. And the technology is in hand to handle the waste problem safely. The reasons we're not moving ahead now are institutional, social, and political. The vitrification of the waste has been demonstrated, so the technology's there to isolate the waste with a high probability that it will never get out to the environment. And the amount of waste is small compared to that from coal. For example, using coal to supply the electricity needs of the average citizen in the United States results in about 5000 lb of waste, of which 500 lb is toxic. Benzopyrene, arsenic lead, and uranium are released from a coal-fired power plant. The same amount of energy from a nuclear plant produces only about five aspirin tablets worth of high-level waste that you have to worry about. So the volume of nuclear waste you have to handle is far less than that for fossil fuels. Also, the impact on the health and safety of the environment is much less with a nuclear power plant than with a coal-fired plant.

Norm Schaffer, P.E. (N. G. Schaffer Engineering, Emmaus, Pennsylvania): Mr. Bovay, what is NSPE doing in regard to President Carter's decision on breeder reactors? Since we are behind other nations in this area, is he reevaluating his position, and could we be helpful with his reevaluation?

Mr. Bovay: I don't think I can answer that except to say that we have a very able legislative and government affairs committee and that we are trying to get our message across, both through our Energy Awareness Foundation, to which you all contribute, and by reaching people at the grass roots. I think you all have heard me say a hundred times that we're not going to reach the federal level with our discussions on this; we've been trying for 15 years. We're going to reach the public at the grass roots: at the PTA, at church, at the Kiwanis Club—wherever you go to talk and wherever our fund can give you the literature and the help you need to talk. The initiative has got to come from our 535 chapters.

Dr. John A. Clark (Professor, Michigan State University): Can you summarize for us the principal conclusions drawn from the Kenemy Commission's study of the Three Mile Island accident?

Dr. Weaver: The Kenemy Commission concluded that the main problem in the Three Mile Island accident was an operator error and that the safety systems certainly held despite the operator insults on those systems. They also concluded that even if a core meltdown had occurred, it would have been contained. In other words, the system would still have protected the public. The industry has responded very well and very quickly to Three Mile Island. It has formed two organizations: one is called NSAC, the Nuclear Safety Analysis Center, in Palo Alto, California; the other is called INPO, the Institute of Nuclear Power Operations. At NSAC they analyze and log data on all safety issues in the nuclear-power industry and inform utilities of generic safety concerns. They're constantly looking at and analyzing safety systems and conditions in plants. The concern of INPO is the training of reactor operators and operating personnel. In my opinion, the weakest link in nuclear-power safety is the operation of the plant. I think Three Mile Island showed that even though you could insult the plant, the safety systems would hold. At INPO they have a very aggressive program of upgrading and accrediting the training of reactor operators; they also will look at plant operations and grade plants on their operations. As a result of this program, the nuclear plant weakest in terms of operating personnel will be as good as the strongest to ensure that we have a complete, strong system of operations in nuclear power plants. This program is going to have a profound effect. I've been following what they're doing; I've been a consultant to them. They're very serious and very thorough. I don't think we'll have another Three Mile Island, because we're really beefing up the training of operating personnel, which has been the weakest part of the safety system.

Glen Capp (Madison, Wisconsin): Since it appears that the news media and politicians are looking at the entire controversial question of nuclear energy from an emotional perspective, it seems that it's part of our responsibility as professional engineers to disseminate facts, to try to bring the whole question into proper perspective with accurate information. What role do you see the universities and educational institutions playing in this effort?

Dr. Weaver: We have a number of our faculty and individuals from other institutions who are actively involved in various public debates on nuclear issues, speaking on television and radio and in public forums. Because we are not directly associated with a particular nuclear power industry in the way that utilities and reactor vendors are, we have credibility. When I have given talks or debated, I've found that many people change their views on nuclear power after getting accurate information. But it takes a lot of effort and a lot of energy to take an active part. We need help, not just from universities, but from every engineer as well. Engineering as a profession has credibility; if you can speak as a professional—not as an instrument of a particular company, but as a professional—you will have credibility.

T. Richard Andresen, P.E. (Brooklyn Park, Minnesota): If action is the antidote to fear, what action can we urge to help the public ease their fear of nuclear energy?

Dr. Weaver: Engineers themselves should become well informed on issues regarding nuclear energy and should actively participate in local and civic organizations' meetings, bringing the facts to the public regarding this energy source. They should speak as professionals and participate in public debate. Only an informed electorate can bring about a national energy policy which makes sense from a technical, social, economic, and environmental point of view.

Marty Rowland (Ferndale, Michigan): Many scientists, engineers, and politicians support the building of a fusion-energy test facility by 1990; do you?

Dr. Weaver: Yes. A recent study entitled *International Tokamak Reactor*,[3] prepared by the world's leading scientists and engineers in fusion technology, indicates that there are no barriers that would prohibit the eventual development of a fusion reactor. A fusion-energy test facility will help solve many of the technological problems in the development of this energy source, which holds great promise for the future; however, it is unlikely that fusion energy will make any major contribution until after the year 2020. In the interim we must rely heavily on coal and nuclear fission to bridge the gap.

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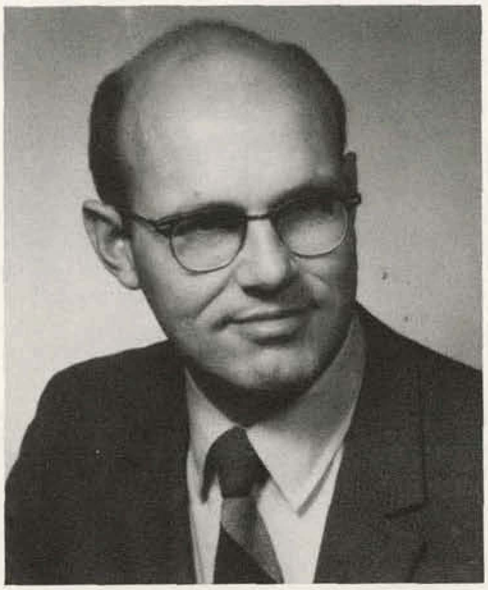
[3]International Atomic Energy Agency, *International Tokamak Reactor: Zero Phase. Report of the International Tokamak Reactor Workshop, Vienna, 1979,* STI/PUB/556 (1980).



Bill A. Stout, P.E.
Coauthor

Bill A. Stout is an agricultural engineer whose interests combine the fields of agriculture and energy. Formerly the department chairman and currently a professor in Michigan State University's Agricultural Engineering Department, he has devoted his attention for the past several years to a variety of energy-related assignments. In 1976 he chaired the Council of Agricultural Science and Technology task force on energy use in agriculture. He has published numerous writings on the subject, including the book *Energy for World Agriculture* for the United Nations' Food and Agriculture Organization. He chairs the Energy Committee of the Michigan Society of Professional Engineers and serves on the **NSPE Energy Committee.** He is also chairman of a 23-member task force that is developing an energy plan for the Department of Agriculture. An extensive computerized information-retrieval system that he developed is now being incorporated into the National Agricultural Library.

Prior to his work in energy, Dr. Stout specialized in agricultural-machinery design. While pursuing his B.S. at the University of Nebraska, he worked as a student engineer in the research department of the John Deere Waterloo Tractor Works. Upon completing his M.S. and Ph.D. degrees at Michigan State University and joining the faculty in 1959, he focused his teaching and research on vegetable- and fruit-harvesting equipment. Later his interests broadened to include international applications of machinery; as a farm power and machinery specialist for the Food and Agriculture Organization, he worked with such diverse applications as hand tools, animal implements, and engine power.

The author of four books and over a hundred scientific papers and the organizer of many international meetings, Dr. Stout is an authority of world prominence on the subject of energy and agriculture.

Nine million barrels of imported oil each day...$98 billion outflow each year at $30 per barrel...Here you have the U.S. energy crisis in a nutshell. Oil imports are expensive and future supplies uncertain. We must develop all domestic energy sources that make technical and economic sense and at the same time learn to manage our precious energy supplies more efficiently.

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John A. Clark
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John A. Clark, a professor of mechanical engineering at the University of Michigan, is a prominent figure in the field of solar energy. He has served as chairman of the board and senior partner of the consulting firm SOLARCON, as a member of the senior planning staff for the North Central Regional Solar Energy Center, and as president of the Central Solar Energy Research Corporation. He has recently been appointed chairman of the Ann Arbor, Michigan, Energy Steering Committee. Dr. Clark holds a B.S. from the University of Michigan and an M.S. and a Ph.D. from the Massachusetts Institute of Technology, all in mechanical engineering. A fellow of the American Society of Mechanical Engineers (ASME), Dr. Clark has served as chairman of the Heat Transfer Division, as an associate editor of *Journal of Heat Transfer,* and as the ASME senior editor for the 1978 International Heat Transfer Conference. In 1956 he was awarded the ASME Heat Transfer Division Memorial Award for significant contributions to the field's permanent literature.

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Paul D. Maycock is director of the Department of Energy (DOE) Photovoltaics Division, which administers a $160-million program dedicated to stimulating the economic viability of photovoltaics in energy-saving applications. Previously, in DOE's predecessor organization, the Energy Research and Development Administration, he was planning coordinator for the Division of Solar Energy. Before joining the federal solar energy program, Mr. Maycock held a variety of executive and research positions with Texas Instruments. Mr. Maycock holds B.S. and M.S. degrees in physics from Iowa State University. The many topics he has researched include solid state physics, thermal diffusion, closed-cycle coolers, ultraviolet radiation in space, extreme-environment electronics, and all aspects of solar energy. He has published articles in *Physical Review, Journal of Metals, Naval Research Reviews, Solid State Electronics,* and *Journal of International Planning* and has written reports for the U.S. Atomic Energy Commission and the U.S. Navy.

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Jes Asmussen, Jr., is a professor of electrical engineering at Michigan State University. He holds B.S., M.S., and Ph.D. degrees in electrical engineering from the University of Wisconsin and is a member of the Institute of Electrical and Electronics Engineers. His research in the area of wind energy has focused on wind-turbine siting, demonstration projects, and manufacturing technology and on the technical and economic feasibility of wind systems applied to municipal utilities. He has also taken part in the planning of the Mid-America Solar Energy Complex in Minnesota. Dr. Asmussen's work has been funded by private industry, the National Science Foundation, the National Aeronautics and Space Administration, and the Department of Energy and its predecessor, the Energy Research and Development Administration.

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Overview of Solar-Energy Technologies: Heating, Photovoltaics, Wind, and Biomass

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PREFACE

It is the position of the National Society of Professional Engineers that all economically feasible domestic energy options must be developed. This means coal; nuclear; and solar in all its forms, including wind, photovoltaics, and biomass. These sources must be coupled with a vigorous conservation program. We need additional energy resources, but we also need to manage what we have more efficiently.

Nearly half our energy needs are provided by oil. Our domestic production is decreasing. Consequently, we are excessively dependent on oil imports.

There are data to support a wide range of opinions about energy. The facts are not always clear. People argue about energy gluts, the pros and cons of rationing, excess profits, overregulation, the need for greater incentives, and so on. It's a bit confusing, isn't it? Sometimes we don't seem to know which way we are going. But clearly, the United States faces an energy dilemma. Jobs, our economy, and even our way of life and political system are in jeopardy. We must solve our energy problems. This paper discusses various alternatives.

One alternative is solar energy, the largest known technically feasible energy source that is environmentally acceptable. Solar energy is abundant but diffuse and intermittent. Uncertain oil supplies and higher prices have focused more attention on solar energy. By the year 2000, over 18 quads per year, or 16% of the nation's energy, could be provided by various forms of solar energy. The federal research, development, and demonstration (RD&D) budget for solar energy has increased from $14.8 million in 1974 to $830 million in 1980. This paper provides an overview of four solar technologies and their associated costs: space and water heating, photovoltaics, wind, and biomass.

Solar Space and Water Heating

A life-cycle model for technical and economic analyses of solar space-heating systems is presented. The model considers the size and cost of the solar collector and other components, the amount of solar energy collected, fuel cost and the escalation rate, the inflation rate, and other factors. Four specific cases are analyzed:

1. Case 1 - investment based on current values;
2. Case 2 - investment based on life-cycle values under a mortgage contract, with allowance for increasing fuel costs;
3. Case 3 - investment of income-producing capital; and
4. Case 4 - investment based on a payback period, with allowance for increasing fuel costs.

The effect of federal and state tax credits on solar heating system economics is analyzed. In Michigan, for example, fuel costs must be more than $8.33 per million British thermal units (Btu) before a specific solar heating system would be competitive with fuel oil or natural gas. With federal and state tax credits, the break-even fuel cost is $3.34 per million Btu. Similar analyses are made for other states.

An economic analysis of domestic solar water-heating systems, using a TI-59 programmable calculator, is also presented. First, the percentage of the yearly water-heating needs that can be met by solar energy is calculated. Then the fuel savings resulting from the solar heating system over its lifespan, the net savings, and the payback period are calculated.

The Department of Energy (DOE) estimates solar heating and cooling potential at 5.6 quads per year by the year 2000.

Photovoltaics

The space program demonstrated that direct generation of electricity from the sun is technically feasible, but the cost of systems has limited their applications. In 1979, solar cell modules cost $6-12 (1980 prices) per peak watt [W(p)]. The DOE goal is to reduce the prices of solar modules to $0.70/W(p) by 1986 and the cost of installed systems to less than $2/W(p). By the year 2000, module prices of $1.10-1.30/W(p) are projected.

The potential contribution of photovoltaic generation is estimated by DOE at 1 quad per year by the year 2000.

Wind

Certain regions of the United States (the high plains from Texas to Nebraska, for example) have wind-power densities exceeding 400 watts per square meter (W/m^2). Many other regions have 200-300 W/m^2. Both large-scale [up to several megawatts (MW)] and small-scale [less than 100 kilowatts (kW)] wind systems are being developed. Utility-interconnected systems are probably the most feasible, although isolated systems may have some applications.

Barriers to widespread use include the current high initial cost and the unproven nature of the product. The payback period and energy balance appear attractive, however. As a result of RD&D efforts, the energy payback period for a large wind turbine generator (WTG) system may be a year or less, depending on the wind regime. For small-scale systems, energy payback may require 3-4 years.

Commercially available WTGs smaller than 40 kW may have economical applications if located at sites with average winds greater than 12 miles per hour. The **best buy** available are WTGs of 40-250 kW; these possess demonstrated economic feasibility if conventional electricity costs are 5-10¢/kilowatt-hour (kWh). Wind potential is estimated by DOE at 1.7 quads per year by the year 2000.

Biomass

Biomass is defined as all organic matter except fossil fuels. It includes residues, crops grown for fuel, marine plants, algae, and other forms. Millions of tons of residues are potentially available for fuel. Fast-growing trees represent one of the largest biomass sources. Opinions vary on the availability of land for biomass production, but over 90% of the 470 million acres of U.S. cropland is of sufficient quality to support biomass production. Soil conservation and environmental constraints require careful attention to prevent mismanagement of the nation's land resources.

Biomass can be burned directly to produce heat or can be converted to liquid or gaseous fuels by a variety of processes, including gasification, pyrolysis, anaerobic digestion, and fermentation.

Liquid fuels are vital to our nation's economy and security. Ethanol has received widespread attention as a gasoline extender and octane booster. Methane could also become an important liquid fuel. Neither appears suitable for diesel fuel, but vegetable oils may have an important role with respect to this engine fuel.

While costs vary with each process, DOE estimates that ethanol could be produced from corn for $1.05/gallon (gal) in a plant that produced 50 million gallons annually. The feedstock [corn @ $2.30/bushel (bu)] represents the largest-cost item ($0.89/gal). If corn prices increased to $3.00/bu, the corresponding ethanol price would be about $1.30/gal.

The total biomass potential is estimated by DOE at 5.5 quads per year by the year 2000.

INTRODUCTION

The sun converts mass into energy at a rate of millions of tons per second. The total amount of energy striking the outer atmosphere of the earth is 35,000 times that used by man. But solar radiation is diffused and intermittent. The cost of collection and storage systems is large. Thus, solar energy provides only a small part of our nation's energy needs, about 4.8 quads (6%) in 1978. By the year 2000, according to estimates made in the *Domestic Policy Review of Solar Energy,* up to 18.1 quads (16%) will be provided by solar technologies (Table 1). Funding from DOE for the federal solar RD&D budget authority has increased from near zero in 1974 to over $800 million in 1980 (Fig. 1).

Solar energy is defined here as the radiation received directly from the sun as well as that derived indirectly through secondary effects such as plant growth and wind. Solar energy is abundant, silent, widely available, and essentially inexhaustible; it requires no fuel, does not damage the environment, and cannot be embargoed by other nations. It is abundant and widely available because the quantity of sunlight falling on the earth's surface is sufficiently large to be made useful in processes in most parts of the world. Solar energy is inexhaustible in terms of the sun's life expectancy: 30-40 billion years. This time span exceeds that of any human projection for earthly questions of economics and energy.

Table 1. Energy contribution by solar technologies, 1978 and 2000 (quads)

	1978	2000
Residential/commercial space heating, cooling, and water heating	Small	2.0
Passive heating	Small	1.0
Industrial/agricultural process heat; onsite electricity, heating, and hot water		2.6
Biomass	1.8	5.5
Solar thermal electrics		0.4
Wind		1.7
Photovoltaics		1.0
Hydro	3.0	3.8
Ocean thermal energy conversion		0.1
Total	4.8 [a]	18.1 [b]

[a] This figure represents 6.2% of the 77.6 quads consumed.
[b] This figure represents 15.9% of the projected consumption, 114 quads.
Source: Department of Energy, *Domestic Policy Review of Solar Energy*, TID-28834 (1979).

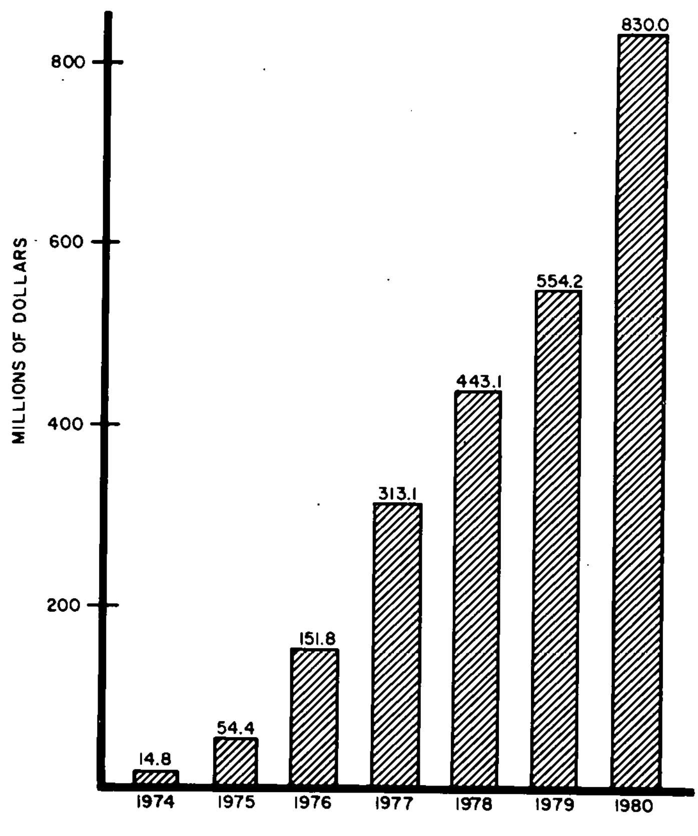

Fig. 1. Funding for federal solar RD&D budget authority (DOE).

However, solar energy also has some disadvantages. It is spread diffusely over the earth's surface and is intermittent. Solar energy is available in significant amounts only when the sun shines. The energy density varies with time. Only when the sun is directly overhead is energy received at the maximum rate. At other times, the rate depends on the angle at which the radiation strikes the earth.

Much of the sun's energy is screened out by the earth's atmosphere or is reradiated into space. The maximum intensity of solar radiation at the earth's surface is about 1.2 kW/m^2. This intensity is encountered only on clear days near the equator at noon. Under these conditions, the total energy received is 6-8 kWh, or 22×10^6 to 29×10^6 joules (J), per square meter per day.

At a radiation intensity of 120 kilocalories (kcal) (5×10^6 J) per square centimeter (c^2) per year, the solar energy falling on about 59×10^5 hectares (ha), or 59,000 square kilometers (km^2), would meet the total worldwide energy requirement (3×10^{20} J).

However, substantial capital investment is needed to purchase and install equipment for collecting and storing solar energy for converting it to more useful and concentrated energy forms. Overcoming these disadvantages will require considerable research and development. In addition, solar conversion systems must be economically competitive with conventional energy sources. The possibility of such cost reductions is excellent when current high production and installation costs are compared with the opportunities for improvement that are now available and awaiting adoption. Bringing costs down through design innovation and mass production will be the major challenge of solar technology from the start of the 1980s to the century's end. Furthermore, high-volume production will be required to meet the national goals for solar-energy conservation.

Each solar technology exhibits its own unique characteristics, economics, and time scale. Although few solar technologies are likely to make a significant contribution before the 1990s, solar space and water heating is gaining widespread acceptance in certain parts of the country. Solar water heaters are marketed commercially, and lifetime costs seem reasonably competitive.

Solar collector systems can be used for both heating and cooling of residences. Solar space heating will soon be competitive with conventional heating systems, but cooling applications are less viable at present.

Photovoltaic generation of electricity has potential as well. Photovoltaic cells convert solar radiation directly into electricity. Silicon cells with a solar-energy collection efficiency of over 15% are currently used to power space vehicles. Their present high cost ($20/W) limits the practical use of these devices. Price levels will probably not be attractive until after 1990.

Wind machines also provide a practical means of generating electricity. Utility-interfaced systems offer the greatest energy potential for wind-electric generation. These systems would cover large geographical regions both on land and offshore, providing energy on demand.

Finally, the use of biomass fuels is attracting great interest throughout the world. Biomass, a form of solar energy resulting from the photosynthetic conversion of solar energy to plants or microorganisms, includes all organic matter except fossil fuels. Dry biomass, including municipal wastes, can be burned to produce heat, steam electricity, or all of these. Also, it can be converted to liquid or gaseous form by anaerobic or alcoholic fermentation, gasification, and other technologies.

The use of biomass for fuels raises complex and widely diverse issues. Impacts must be assessed for each specific feedstock, geographic area, conversion technology, and end-use application. Millions of tons of biomass could be available for fuel.

Each of the four sources considered here will be discussed in detail in the following sections.

SOLAR HEATING SYSTEMS

A Life-cycle Model for Solar Space Heating[1]

The model presented here, the life-cycle analysis, focuses on the technical and economic performance of a solar heating system over an extended time period. An annual or a more simple model offers certain advantages. Such models permit simple and inexpensive calculations for practical use in preliminary design analyses and feasibility studies.

Analysis

Nomenclature. The list below defines the variables used in the analysis that follows.

a	=	fuel cost escalation rate, \$/\$-yr
A_c	=	collector area
A_o	=	solar input parameter, Btu/deg-day-ft^2
b	=	a constant, introduced to maintain dimensional homogeneity
$\overline{C}$	=	annual cost, \$
C	=	total life-cycle cost, \$
C_F	=	fuel cost after inflation
C_{Fo}	=	initial fuel cost, \$/Btu
C_o	=	installed collector system cost, \$/ft^2
d	=	a constant, introduced to maintain dimensional homogeneity
$F_i(a,t)$	=	inflation function
F_s	=	fraction of annual load supplied by solar
F_o	=	solar input parameter
I	=	capital recovery factor, \$/\$-yr
R_{LC}	=	U^*A/A_c

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[1]For more detail, see J. A. Clark, A Life-cycle Model for Solar Heating System Design and Economic Evaluation. Second Annual Energy Seminar. Gannon University, Erie, Pennsylvania, March 31-April 1.

t	=	time, yr
T	=	tax rate, \$/\$-yr
U·A	=	building load factor, Btu/deg-day
θ	=	annual heating degree days, deg-days
n_f	=	conversion efficiency of backup system

The annual cost, $\overline{C}$, of a solar heating system considering costs of investment capital, taxes, and operation (fuel) is

$$\overline{C} = C_o(I + T)A_c + (1 - F_s)(U{*}A)\theta\, C_F/n_F \quad . \tag{1}$$

Introducing A_c, R_{LC}, and rearranging terms gives:

$$\frac{\overline{C}}{(U{*}A)\theta/n_F} = F_s \frac{C_o(I + T)}{(\theta/n_F)A_o(1 - F_s/F_o)} + (1 - F_s)C_F \quad . \tag{2}$$

During a period of inflationary and market-induced fuel-price increases, the cost of fuel, C_F, is expressed as

$$C_F = C_{F_o}(1 + da)^{bt} \quad . \tag{3}$$

in which b and d are introduced only to maintain dimensional homogeneity.

This result is introduced into Eq. (2) which then can be integrated over any period of time, t, to obtain the technical-economic result known as a life-cycle analysis. This result, written in dimensionless form for convenience, is

$$\pi_1 = \pi_2 \left| \frac{\pi_3}{1 - \pi_2} - \pi_4 \right| + 1 \ , \tag{4}$$

where

$$\pi_1 = \frac{C/C_{F_o}}{(U{*}A)(\theta t/n_F)F_1(a,t)} \ , \tag{5}$$

$$\pi_2 = \frac{F_S}{F_o} \ , \tag{6}$$

$$\pi_3 = \frac{(C_o/C_{F_o})(I + T)}{(\theta/n_F)(A_o/F_o)F_1(a,t)} \ , \tag{7}$$

$$\pi_4 = F_o \ ,$$

and $F_1(a,t)$, the inflation function is

$$F_1(a,t) = \frac{(1 + da)^{bt} - 1}{bt\log_e(1 + da)} \ , \tag{8}$$

Results

A clearly defined minimum value in π_1 (hence, in the life-cycle cost, C) is evident at certain values of π_3 and π_2 (or, the solar fraction at a given location). The first minimum in π_1 (or, life-cycle cost, C) is $F_s = 0$ ($\pi_2 = 0$) for π_3 equal to F_o. This occurs when when

$$\pi_3 \doteq \frac{(C_o/C_{F_o})(I + T)}{(\theta/n_F)(A_c/F_o)F_1(a,t)} = F_o \quad . \tag{9}$$

Accordingly, no minimum in π_1 (or, life-cycle cost) can exist if π_3 is $>F_o$.

Thus, the circumstances of operation and cost first capable of producing a minimum life-cycle cost (or, optimization) would correspond with Eq. (9). Any combination of variables resulting in $\pi_3 \leqslant F_o$ would correspond to an economically optimum system. Therefore, economically optimum systems have a minimum life-cycle cost for a fixed set of operational and cost parameters (Figs. 7 and 8). The data in these figures are the **break-even** costs (at the meter) of conventional fuels, at which the life-cycle costs for a solar-heated residence would be exactly the same as the costs for a conventionally heated residence. Two sets of data are given for time in several U.S. locations. The upper figure is the **break-even** (metered) cost of fuel without the consideration of federal and state incentives (tax credits), while the lower figure is the corresponding cost after the effect of these tax credits is included. Clearly, these financial incentives have a pronounced influence on propelling solar space heating to economic competitiveness with conventional heating systems in many U.S. locations.

Annual Cost Analysis of Solar Supply Systems[2]

Nomenclature. The list below defines the variables used throughout the section that follows.

A_c	=	collector area, m^2 or ft^2
a	=	annual inflation rate, \$/\$-yr
B	=	property equity factor
b	=	constant, 1.0 yr^{-1}
C_c	=	annual cost conventional system, \$/yr
$C_{c,mm}$	=	annual cost to conventional system for materials in maintenance, \$/yr
$C_{c,ML}$	=	annual cost to conventional system for labor in maintenance, \$/yr
$C_{s,MM}$	=	annual cost to solar system for materials in maintenance, \$/yr
$C_{s,ML}$	=	annual cost to solar system for labor in maintenance, \$/yr
$C_{a,MM}$	=	annual cost to auxiliary system for materials in maintenance, \$/yr
$C_{a,ML}$	=	annual cost to auxiliary system for labor in maintenance, \$/yr

[2]J. A. Clark, "General Principles," chap. 6 of Economics of solar energy and conversion systems, vol. 1, ed. by Frank Kreith and R. E. West, CRC Press, West Palm Beach, Florida, 1979.

C_B = cost of conventional furnace, $

C_s = annual cost of a solar heating system, $/yr

C_a = annual cost of auxiliary (conventional) heating system, $/yr

C_o = cost of solar system per unit area of collector, $\$/m^2$ or $\$/ft^2$

$C_{s,a}$ = annual cost of solar/auxiliary heating system, $/yr

c = constant, 1.0 yr

C_c^* = cost of collector, $\$/m^2$ or $\$/ft^2$

C_s^* = cost of storage per unit volume of storage, $\$/m^3$ ($\$/ft^3$)

C_E^* = cost of equipment and controls for solar system per unit area of collector, $\$/m^2$ or $\$/ft^2$

C_F^* = unit cost of fuel, $/J ($/Btu)

C_p^* = unit cost of power, $/J ($/Btu)

E_o = annual useful energy per unit area of collector, Eq. (5), J/m^2-yr (Btu/ft^2-yr)

$\overline{E}$ = mean value of useful energy per unit area of collector, Eq. (9), J/m^2-yr (Btu/ft^2-yr)

n_F = furnace efficiency

n_o,n = annual collector efficiency

F_a = fraction of year auxiliary system provides heating

F_s = fraction of year solar system provides heating

F_u = utilization factor for solar system

F_c = fraction of clear sky solar radiation incident on collector, Eq. (1)

F_t = see Eq. (16)

F_1 = inflation factor, Eq. (10)

F_2 = inflation factor, Eq. (14), yr

h = heat transfer coefficient, w/m^2-C (Btu/hr-ft^2-F)

I = cost recovery factor, $/$-yr

i_d = annual discount rate (interest) on mortgage, $/$-yr

i = annual interest on investment, $/$-yr

P_c = annual power requirements, conventional system, (J/yr or Btu/yr)

P_s = annual power requirements, solar system, (J/yr or Btu/yr)

P_a = annual power requirements, auxiliary system, (J/yr or Btu/yr)

Q_a = annual heating load, (J/yr or Btu/yr)

$(Q/A_c)_o$	=	total annual clear sky solar flux per unit area of collector, J/m^2-yr (Btu/ft^2-yr)
(Q/A_c)	=	total annual clear sky solar flux per unit area of collector, J/m^2-yr (Btu/ft^2-yr)
R_I	=	investment ratio
R_o	=	investment ratio (Case 1), Eq. (4)
R_ℓ	=	investment ratio (Case 2), Eq. (7)
R_i	=	investment ratio (Case 3), Eq. (13)
R_t	=	investment ratio (Case 4), Eq. (18)
S	=	income tax rate, %
T	=	tax rate, \$/\$-yr
t	=	time, yr
θ	=	thermal parameter, J/deg-day (Btu/deg-day)
t_*	=	useful life, yr
U	=	overall heat transfer coefficient, W/m^2-c (Btu/hr-ft^2-F)
V_s	=	volume of storage unit, m^3 or ft^3
X_I	=	insulation thickness, m or ft

Conversion Factors. The factors allow conversion from english to metric units.

$$\text{Btu/ft}^2\text{-yr})\ 11{,}356.528 = \text{J/m}^2\text{-yr}$$

$$\$/\text{ft}^2)\ 10.764 = \$/\text{m}^2$$

$$\frac{\text{Btu/yr}}{\$})\ 1055.056 = \frac{\text{J/hr}}{\$}$$

$$\text{Btu})\ 1055.056 = \text{J}$$

To examine the economic viability of a solar energy conversion system, a model is adopted consisting of two buildings, one receiving heat and hot water by conventional methods and another supplied with heat by a combination of conventional and solar systems. Annual total costs of each system are compared. Costs for maintenance and insurance are not included explicitly but could be considered by increasing the annual investment charges.

The annual cost differential between a conventional heating system and a solar/auxiliary heating system then becomes:

$$\Delta C = \frac{Q_a C_F^*}{n_F}(1-F_a) - \left[C_c^* + C_s^*\left(\frac{V_s}{A_c}\right) + C_E^*\right] A_c(I+T) \ . \tag{1}$$

The result in Eq. (1) provides the basis for constructing several technical/economic models for evaluating the economic viability of a solar-energy heating system. Four economic models are presented that are appropriate to this decision. These models, which allow for increasing fuel costs with time, include economic/technical evaluation of solar-energy heating systems for investment: (1) at a given time, (2) under a mortgage contract, (3) by use of personal or corporate capital, and (4) on the basis of a payback period. No single economic criterion exists for determining whether or not a solar-energy heating system is economically feasible.

However, a criterion for evaluating a economic viability of a **proposed** solar energy heating system can be developed. Whenever the differential cost between a conventional heating system and one consisting of a solar/auxiliary system is equal to or greater than zero, the solar/auxiliary system is economically justified. This criterion is expressed as

$$\frac{\Delta C}{A_c} \geqslant 0 \tag{2}$$

This criterion may be written in another, somewhat more useful, form:

$$R_o = \frac{F_u F_e (Q/A_c)_o C^*_{F_o} n_o/n_F}{\left| C^*_c + C^*_s \left(\frac{V_s}{A_c}\right) + C^*_E \right| (I + T)} \geqslant 1.0 \ . \tag{3}$$

Case 1: Investment Consideration Based on Current Values[3]

The investment ratio, R_o, for this case is given in Fig. 2 as a function of $(I + T)/C^*_{F_o}$ and E_o/C_o. The range of $(I + T)/C^*_{F_o}$ includes values of this parameter that currently exist in the United States and encompasses values that may exist in the future as taxes and cost of fuel and investment change. The factor, R_o, can be written as

$$R_o = \frac{(E_o/C_o)}{(I + T)/C^*_{F_o}} \ , \tag{4}$$

where

$$E_o = F_u F_e (Q/A_c)_o \frac{n_o}{n_F} , \ J/m^2\text{-yr}, \ (Btu/ft^2_c\text{-yr}) \tag{5}$$

$$C_o = C^*_c + C^*_s(V_s/A_c) + C^*_E, \ \$/m^2, (\$/ft^2_c) \ . \tag{6}$$

When $R_o > 1$, a solar heating system can be judged as economically viable under any given **current** conditions of geographic location, selected design, and economic costs. When $R_o < 1$, the opposite is true.

[3]For these calculations, C_o was taken as \$25/ft² \$269.10/m², a cost which is probably low to mean for installed equipment in the United States (1980); and n_o was set at 0.40, a reasonable estimate for solar and meteorological conditions prevailing over most of the United States and available from current solar collector designs. The furnace efficiency, n_F, was taken as 80%, a representative value for a good furnace.

The approximate ranges of the controlling parameters for mid 1976 indicate that solar space heating is not now an economically attractive investment compared with nonelectrical heating (Fig. 2). In this case, system costs currently are 2-3 times the annual value of the fuel savings, a poor investment proposition. However, solar heating is economically more attractive than electrical heating, particularly in the southwestern regions, where E_o/C_o is high (Fig. 2). Clearly, some changes are needed to improve the economic viability of solar heating systems.

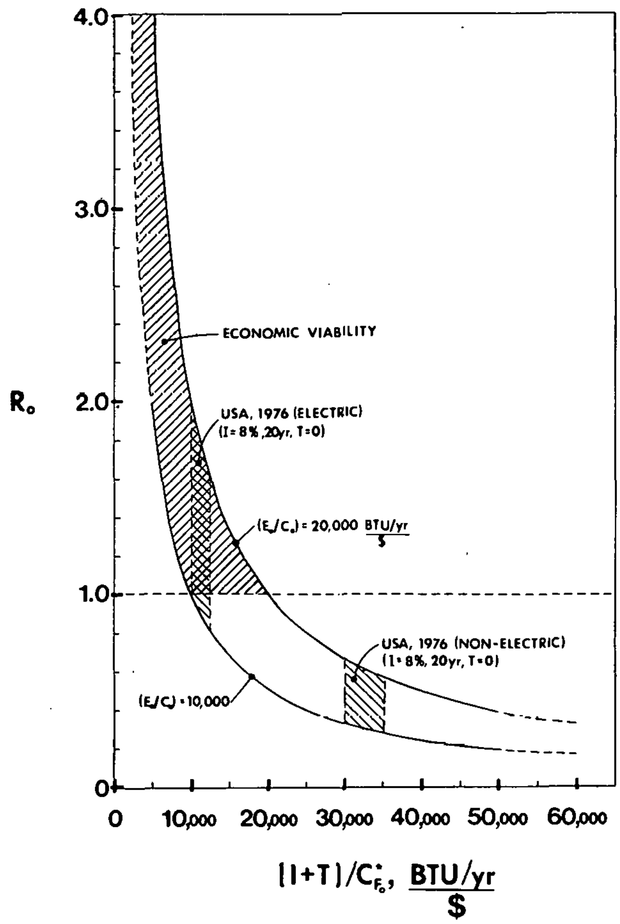

Fig. 2. Investment ratio, R_o (Case 1).

One important economic parameter is $(I + T)/C^*_{F_o}$. This is the ratio of the sum of the rates of investment costs and taxes to fuel cost under **current** circumstances. Hence, it is not only fuel costs that determine the economic attractiveness of solar energy systems, as is often supposed, but rather the ratio of the investment-plus-ownership costs to fuel costs that represents a significant economic parameter. Fuel and energy costs are estimated to increase at 200-400% for gas, oil, and electricity by the year 2000. These increases alone will do much to propel solar energy systems to economic viability, perhaps as early as 1985.

Another parameter influencing R_o is the ratio E_o/C_o. This ratio involves operational considerations (F_u, n_F), geographic location and meteorological effects $[F_e$ and $(Q/A_c)_o]$, design (n_o), and the material and labor costs to manufacture, transport, and install a solar energy system (C_o). The latter costs are also geographically dependent owing to shipping distance and labor costs variables between different sections of a country. Tax credits reduce costs and contribute significantly to the economic viability of solar energy systems.

Significant improvements are expected in the costs of manufacturing and installing solar collectors. Apparently, the growth of solar energy systems hinges on reducing the cost of collectors through innovative design and mass-production techniques.

Case 2: Investment based on life-cycle values under a mortgage contract, with allowance for increasing fuel costs

This is perhaps the most realistic of all the economic models discussed, because it allows for economic evaluation based on integrated costs and fuel savings over an extended time period; these aspects are not considered in the **current-value** model in Case 1.

The formulation for the **instantaneous** (annual) values that determine economic viability [i.e., the inequality in Eq. (3)] can be rearranged slightly and integrated in time to produce

$$R_\ell \equiv \frac{(\bar{E}/C_o)F_1(a,t)}{(I+T)/C^*_{F_o}} \geqslant 1.0 \ , \tag{7}$$

where the cost of fuel presumably escalates according to

$$C^*_F = C^*_{F_o}(1+ca)^{bt}, \tag{8}$$

and

$$\bar{E} = \left| F_u F_e (Q/A_c) \frac{n}{n_F} \right|_{nn} \tag{9}$$

or,

$$F_1(a,t) \equiv \frac{(1+ca)^{bt}-1}{bt \, \mathrm{Log_e}(1+Ca)} \ . \tag{10}$$

In this result, $\mathbf{R_\ell}$ is the investment ratio for a fixed-rate mortgage. It is a function of the additional variables of the time period (life-cycle) and inflation rate on fuel costs. $\mathbf{R_\ell}$ must be > 1 before an investment in a solar energy heating system is economically viable considering life-cycle costing and increased fuel costs during the life of the equipment and the mortgage.

The investment ratio for this economic evaluation for a 20-yr life-cycle, $\mathbf{R_\ell}$ is shown in Fig. 3 [see Eq. (7)]. The values of $\bar{E}/C_o$ of 10,000-20,000 Btu/yr-$ (10.551×10^6 - 21.102×10^6 J/yr-$) are roughly the limits that were expected within the continental United States in 1976 and represent a combination of available solar energy and system performance and costs that were current in this region. Two fuel-cost escalation rates are also shown for the 20-yr period [i.e., 0.05 and 0.10 $/$-yr].

For the past several years, the annual rate of increase in the cost of petroleum products, natural gas, and electricity in the United States has been greater than 15% and as high as 65%. While these rates may be high and might not be sustained over longer periods, no evidence in the world's energy and fuel markets suggests a price stabilization. Accordingly, the annual inflation rates of 5 and 10% for a 20-yr life-cycle period may prove reasonable.

Based on a 20-yr investment (even with an annual inflation rate of 5%), a solar heating system is economically competitive with nonelectric fuels in the sunshine abundant regions of the United States, $\bar{E}/C_o = 20{,}000$, or for those circumstances in which present solar system costs could be cut in half. A greater annual inflation rate will enhance the economic attractiveness of such an investment. Further, any combination of reduced investment costs and reduced taxes with a corresponding increase in fuel cost, $C^*_{F_o}$, also creates a favorable economic condition for investment in solar-energy systems.

The Internal Revenue Service income tax code allows an income tax deduction for interest payments made on loans, including mortgage contracts. The effect of such a deduction on the income tax paid depends on an individual's tax rate. A modified criterion including this effect is

$$R_{\ell,s} = \frac{(\bar{E}/C_o)F_1(a,t)}{(1+T)^*/C^*_{F_o}} \geqslant 1.0 \tag{11}$$

where

$$\frac{(I+T)^*/C^*_{F_o}}{(I+T)/C^*_{F_o}} = 1 - \frac{S}{(I+T)} \left| I - F_1(i_d,t)(I - i_d) \right| . \tag{12}$$

This ratio will always be equal to or less than one, thus reflecting the influence of an income tax credit, which enhances the economic viability of an investment in a solar-energy-conversion system.

The ratio in Eq. (12) is given in Table 2 for discount interest rates of 4, 8, and 12% and for values of S/(I+T) of 0, 1, 2, 3, and 4 for mortgage terms up to 30 years.

Income tax credits on interest payments significantly influence the economic viability of an investment in a solar energy system. In Cases 1 and 2, the maximum benefits range from 16-48% for the higher income tax rates. For the more common 20-yr mortgage at discount interest rates of 8 and 12%, this effect is 20 and 33%, respectively. In terms of the conditions shown in Fig. 3 (8%, 20-yr mortgage), a 20% income tax credit effect shifts the shaded portion (nonelectric heating) on the horizontal axis to the left to an approximate value of 26,000. This improves the economic viability of the investment. For lower income tax rates, the influence on improved economic viability is less (see Table 2).

Case 3: Investment of income-producing capital

This case corresponds to a situation in which an individual or a corporation considers using its own capital, rather than borrowed capital, for investment in a solar heating system. Two limiting subcases can be identified as those in which allowance for equity (through resale) of the solar system is considered at a minimum (Case 3a) and maximum (Case 3b) value in the economic evaluation. These limiting cases are identified by the value of the parameter B. The influence of income tax assessments on interest income that would

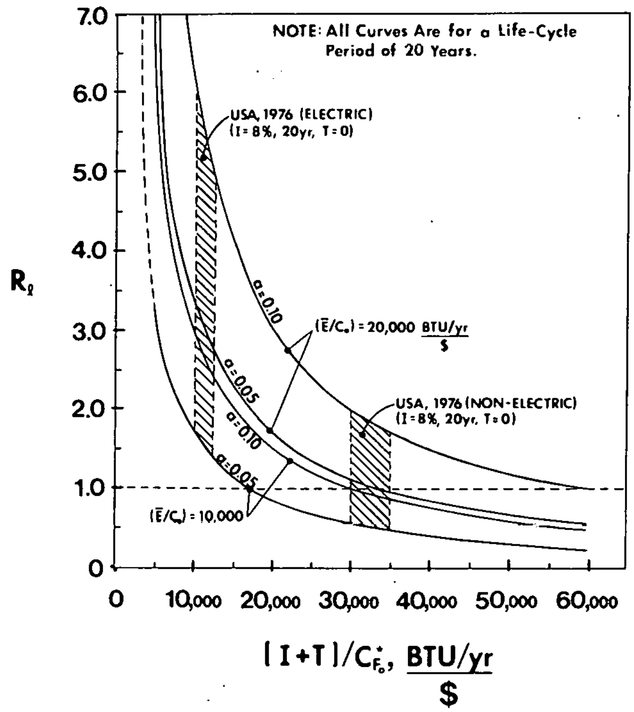

Fig. 3. Investment ratio, R_ℓ, for a 20-year period (Case 2).

Table 2. Values of $\dfrac{(I+T)^*/C^*_{F_o}}{(I+T)/C^*_{F_o}}$, Eq. (12), for various investment conditions

(a) i_a = 0.04 (4%)

Term years	S (I + T) 0	1	2	3	4
1	1.0	0.97987	0.95974	0.93961	0.91948
10	1.0	0.97870	0.95738	0.93609	0.91478
20	1.0	0.97741	0.95482	0.93224	0.90965
30	1.0	0.97617	0.95233	0.92850	0.90466
∞	1.0	0.96000	0.92000	0.88000	0.84000

(b) i_a = 0.08 (8%)
S (I + T)

Term years	0	1	2	3	4
1	1.0	0.95949	0.91897	0.87846	0.83795
10	1.0	0.95492	0.90984	0.86476	0.81968
20	1.0	0.95012	0.90024	0.85037	0.80049
30	1.0	0.94582	0.89164	0.83747	0.78329
∞	1.0	0.92000	0.84000	0.76000	0.68000

(c) i_a = 0.12 (12%)
S (I + T)

Term years	0	1	2	3	4
1	1.0	0.93887	0.87773	0.81660	0.75547
10	1.0	0.92890	0.85781	0.78671	0.71561
20	1.0	0.91906	0.83813	0.75719	0.67626
30	1.0	0.91115	0.82230	0.73346	0.64461
∞	1.0	0.88000	0.76000	0.64000	0.52000

have been produced on the invested capital if the capital had not been used for the solar system is examined in Case 3c.

The economic model for these cases is formulated using the inequality in Eq. (3) in a slightly revised form. The basis for this model is that a solar heating system is economically viable when the value of fuel savings plus any property equity that may accrue for the system over a period of time is equal to or greater than the increase in value that would have been obtained had the original capital been used in an interest-bearing investment. Hence, economic viability exists over period t when the investment ratio, R_i, is

$$R_i \equiv \frac{\left(\frac{E}{C_o}\right) C^*_{F_o}\ F_2(a,t) + B \left| 1 - \frac{t}{t^*} \right|}{(1 + ci)^{bt} - 1} \geqslant 1.0 \tag{13}$$

where

$$F_2(a,t) = \frac{(1 + ca)^{bt} - 1}{b \log_e(1 + ca)}$$

$$= F_1(a,t) \cdot t \ . \tag{14}$$

As in the previous cases, economic viability in this mode of investment exists only when $R_i \geqslant 1$ as in Eq. (13).

The ratio R_i is given in Figs. 4 and 5 for two annual inflation rates, 10 and 15%, and for the two limiting values of the property equity factor, B. This is the determining factor in Cases 3a and 3b; in Case 3a, B = 0 and in Case 3b, B = 1. In each figure, the rate of expected interest, i, is 8%, a value close to that currently obtained fairly easily for many common U.S. investments.

Note the strong influence that fuel escalation costs have on the economics of this type of investment and the effect of including equity in the solar system. An increase in the inflation rate from 10 to 15% usually results in a viable economic investment after 7 years for regions with the larger $(\bar{E}/C_o)C^*_{F_o}$ value (the southwestern United States, for example) and after 22 years for those having the smaller value (generally the eastern half of the United States), even when equity is not a factor (Fig. 5). Lower inflation rates extend these periods of economic viability (Fig. 4) about 20 years for the larger $(\bar{E}/C_o)C^*_{F_o}$ value. There is no reasonable economic investment for a fuel-cost escalation rate of 0.10 yr^{-1}.

The effect of property equity (B > 0) changes the economic picture significantly. For both rates of fuel-cost increase, the influence of maximum equity (B = 1) is to create a favorable economic condition during the initial investment periods (generally up to 15 yr). During this time the combination of fuel savings and property equity are considered greater than any income realized on an 8% investment, compounded annually. At some point in time these two effects balance (shown in Figs. 4 and 5 by a minimum in the curves).

The minimum value is R_i less one for all conditions except those corresponding to the higher inflation rates and $(\bar{E}/C_o)C^*_{F_o}$ values. Once this minimum is reached the economic attractiveness of the investment improves with time, due to increased fuel-cost savings compared with the potential return on the interest-bearing investment. The two cases, B = 0 and B = 1, merge when the period of investment equals the useful life of the system. Beyond this time, there is a small negative difference between the two cases (dotted curves), indicating a cost penalty in disposing of equipment whose useful life has been exceeded.

The two previous cases 3a and 3b do not consider the effect of income taxes paid on the interest earned on C_o had it been invested rather than used to purchase a solar-energy system; the following case, 3c considers that effect. Income taxes are levied annually, so the effect of such taxes is obtained by evaluating the interest income between years k-l and k and integrating the total taxes over a period, t. No secondary tax effects will be considered as the tax and interest rates are those expected to represent effective mean values over the specified time period. The effect of income taxes is measured by multiplying the investment ratio, R_i, of Cases 3a and 3b by a factor, F_t, to obtain a new investment ratio, $R_{i,t}$. That is,

$$R_{i,t} \equiv F_t R_i \geqslant 1.0 \tag{15}$$

where

$$F_t = \left| 1 \frac{is}{(1 + ci)\, b \operatorname{Log}_e (1 + ci)} \right|^{-1} . \tag{16}$$

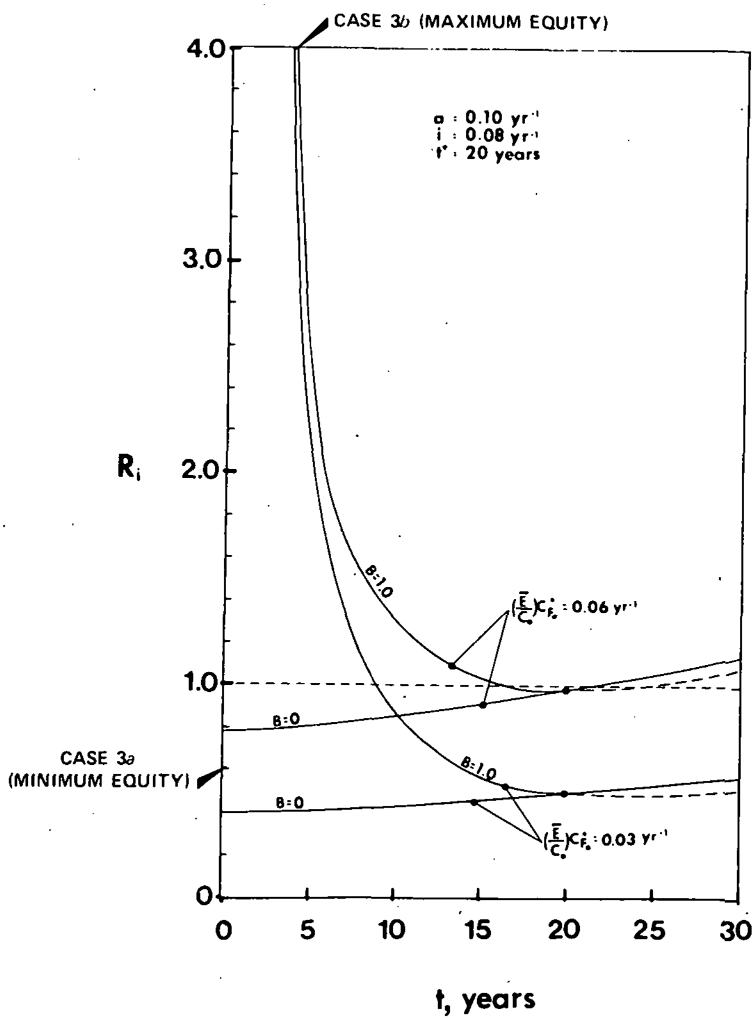

Fig. 4. Investment ratio, R_i (Case 3a = 0.10 \$/\$-yr).

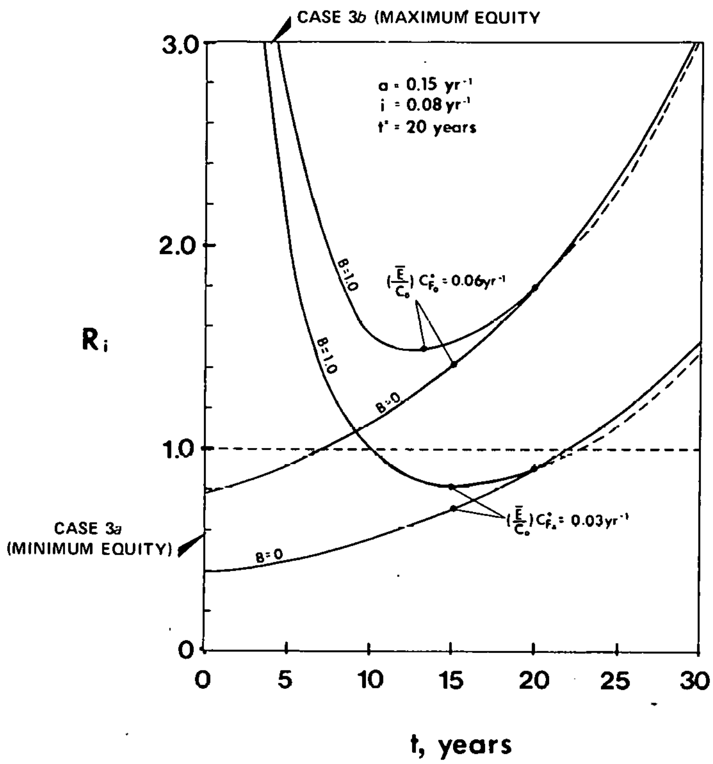

Fig. 5. Investment ratio, R_i (Case 3a = 0.15 \$/\$-yr).

Numerical values for F_t are given in Table 3 for interest rates of 4, 8 and 12% and income tax rates of 0, 20, 30, 40, and 50%.

Table 3. The function F_t to account for income tax assessment (Case 3c)

S,%	i=0.04 (4%)	i=0.08(8%)	i=0.12(12%)
0	1.0	1.0	1.0
20	1.24398	1.23839	1.23317
30	1.41682	1.40597	1.39592
40	1.64543	1.62600	1.60815
50	1.96202	1.92769	1.89648

Income tax assessment has a major influence on making a solar system an economically attractive investment when compared with a straight interest earning investment. The values of F_t (Table 3) can be used directly with the results in Figs. 4 and 5. The effect is to move the curve upward by as much as 92%. Note that the interest rate obtained is much less of an economic factor than is the income tax rate.

Case 4: Investment based on payback period with allowance for increasing fuel costs

This discussion is often valuable for those considering purchases of tools, machinery, or physical systems capable of producing income or reducing operational costs. An evaluation of the period to pay off initial investment using income or savings from the purchased systems follows. Using the same assumptions as in previous cases, ignoring any possible equity in property,[4] and allowing for escalation of fuel costs, the criterion for this case is

$$\bar{E}\, C^*_{F_o} \int_o^t (1 + ca)^{bt}\, dt \geq C_o \ . \tag{17}$$

Defining the investment ratio as R_t for this case, the inequality above becomes

$$R_t \equiv \left(\frac{\bar{E}}{C_o}\right) C^*_{F_o}\, F_2(a,t) \geq 1.0 \ . \tag{18}$$

The investment ratio, R_t, is given in Fig. 6 as a function of time and of several annual inflation rates for $(\bar{E}/C_o)C^*_{F_o}$ values of 0.03 and 0.06 yr^{-1}. An economically viable investment for this case exists when $R_t \geq 1$. The payback period is that time for which $R_t = 1$. Even a mild inflation significantly affects the payoff period: an increase in inflation from zero to 5% reduces the pay period from about 33 years to 20 years for a circumstance in which $(\bar{E}/C_o)C^*_{F_o}$ is 0.03 yr^{-1}.

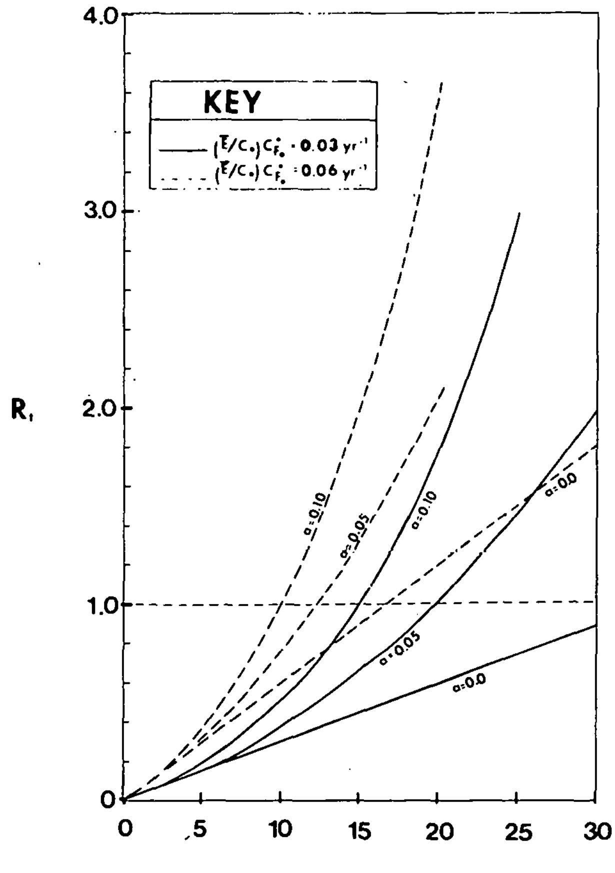

Fig. 6. Investment ratio, R_t (Case 4).

[4] If the payback period is less than the useful life of the equipment, equity in the system could be considered using the formulation presented in Case 3. An investment under Case 4 would then appear more attractive.

Some measure of the economic reliability of this case may be obtained by comparing it with some results from Case 2. For an annual inflation rate of 5%, the payback period for Case 4 is 20 years when $(\bar{E}/C_o)C^*_{F_0}$ is 0.03 yr^{-1} (Fig. 6). In the life-cycle analysis (Case 2), for an 8% 20-yr. mortgage (i.e., 20-yr payback period) the value of R_ℓ for an inflation rate of 5% and $\bar{E}/C_o$ of 10,000 [roughly the same as $(\bar{E}/C_o)C^*_{F_0}$ of 0.03 for $C^*_{F_0}$ equal to \$3 per 10^6 Btu] is only about 0.5, indicating an unattractive investment. If a 20-yr payback period is advantageous in this circumstance from the criterion of Case 4, a contradiction is evident when examined under the more realistic conditions presented in Case 2.

The same conclusion is found by a comparison of this example under Case 4 with that in Case 3a or 3b for a 20-yr term in a situation where capital could have been invested at 8% compounded interest. In this instance, R_i is only 0.278, indicating that an income-producing investment would have been a more economically viable decision as opposed to borrowing capital at 8% interest under a 20-yr mortgage for installing a solar heating system or making a decision to install such equipment on the basis of a seemingly favorable 20-yr payback period. However, under other circumstances, such as a higher annual rate of inflation, lower collector costs, reduced investment costs, etc., economic viability of solar heating systems will be realized.

Tax credit effect on break-even fuel costs [5]

The effect of tax credits, federal (1980) and state (1979), on the solar break-even metered fuel costs for both electrical resistance and fossil fuel backup systems is given in Figs. 7 and 8. The **break-even** cost is the metered cost of fuel which results in a solar system costing the same as a conventional system over a period of time for an assumed set of conditions.

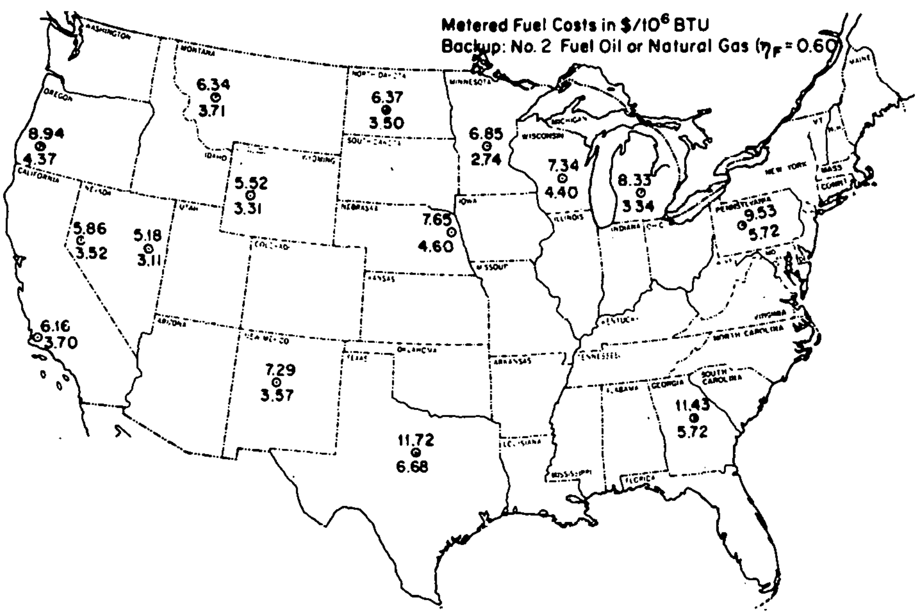

Fig. 7. Effect of Tax Credits on Break-Even (Metered) Fuel Costs, $(C_{F_0})_{MIN}'$ for Solar Space Heating. Backup Energy: No.2 Fuel Oil or Natural Gas (Conversion Efficiency: 60%). Units: \$ per Million BTU at Meter. **Upper Figure:** Without Tax Credits; **Lower Figure:** With Tax Credits. Data Include Both Federal (1980) and State Credits (1979), Where Available. Source: John A. Clark, *A Generalized Analysis of Solar Space Heating in the United States*, University of Michigan, Ann Arbor, (1980).

[5] The data regarding tax credits were obtained from the following: State Solar Legislation (Updated to 1980), Department of Housing and Urban Development, National Solar Heating and Cooling Information Center, Rockville, Maryland; Federal Energy Tax Act of 1978; and Title II, Energy Conservation and Production Incentives, Part I, Residential Energy Credit, Crude Oil Windfall Profit Tax Act of 1978, P.L. 96-223 (April 2, 1980).

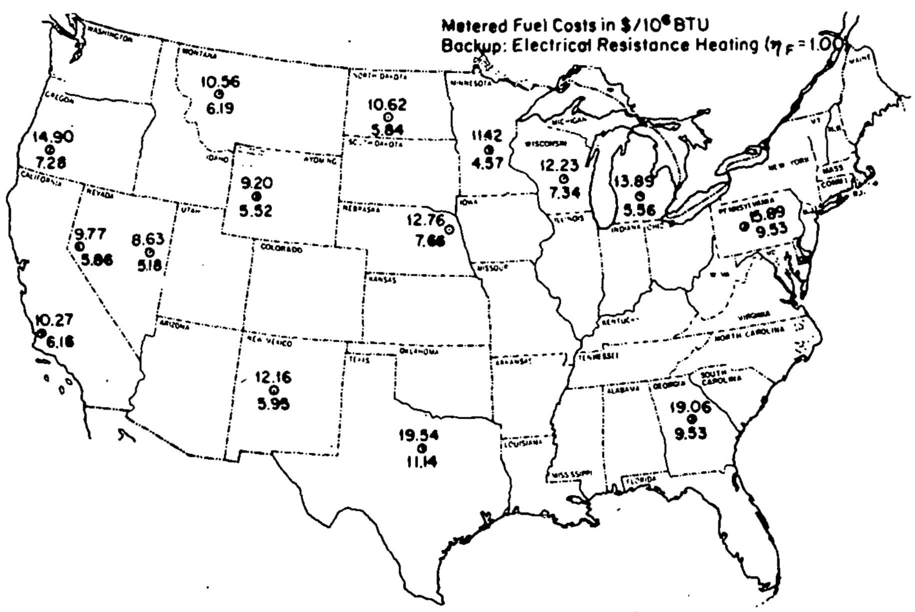

Fig. 8. Effect of Tax Credits on Break-Even (Metered) Fuel Costs, $(C_{F_0})_{MIN}$, for Solar Space Heating. Backup Energy: Electrical Resistance Heating (Conversion Efficiency: 100%). Units: $ per Million BTU at Meter. **Upper Figure:** Without Tax Credits; **Lower Figure:** With Tax Credits. Data Include Both Federal (1980) and State Credits (1979), Where Available. Source: John A. Clark, *A Generalized Analysis of Solar Space Heating in the United States*, University of Michigan, Ann Arbor, (1980).

Data are given in dollars per million Btu, and apply to solar space heating, using a single-glazed liquid collector facing south and tilted at an angle equal to the latitude plus 10°

Other conditions are listed below.

Fixed equipment cost, $	1000
Collector and storage/installed cost, $/ft^2	20
Mortgage	13%/yr for 20 years
Maintenance, taxes, and insurance	2%/yr
Building load factor, Btu/deg-day	15,000
Fuel-cost escalation	7½%/yr for 20 years

For different fuel-cost escalation rates, multiply the numbers on the map by the following factor, F, from table below.

Fuel Cost Escalation (%/yr)	F
5	1.325
7.5	1.000
10	0.747
12.5	0.554
15	0.408

Tax credits provided by state legislation are variable. The latest federal legislation on solar tax credits increases the credit from 22% to 40% of the installed cost of the solar system. In most cases, state solar tax credits supplement the federal credits. For example, in Michigan, on the basis of a $10,000 investment, the total tax credit would amount to approximately 65% of the initial investment which may be apportioned over a period of several years. In most instances, the tax credit legislation has terminal dates in the early 1980s, but efforts are underway to extend the legislation.

Cost of Domestic Solar Water Heating Systems [6,7]

Another major use of solar energy is for heating water. The cost of heating water with solar energy is determined using a TI-59 programmable calculator. The objective of the program, based on the f-chart method, is to calculate the potential dollar savings resulting from supplementing a conventional water-heating system with a solar water heater. A life-cycle cost analysis is used to calculate the savings. (For comparison, the costs and efficiencies of conventional water heaters are shown in Table 4.)

Table 4. Cost and efficiencies of conventional water heaters

	Cost million Btu	Btu conversion factors	Efficiency (%)
Lp gas	$ 6.25	96,000 Btu/gal.	60-70
Natural gas	$ 2.30	1,000 Btu/ft^3	60-70
Fuel oil (No. 2)	$ 6.80	138,000 Btu/gal.	50-55
Electricity	$15.00	3,413 Btu/kWh	90-92

Tables 5 and 6 can be used to determine the monthly hot water needs provided by a solar system. First, enter the latitude for the site where the solar collectors are to be placed. If this is not known use the latitude that corresponds to the city from which the insulation data were taken.

Table 5. Data input for calculating percentage of water-heating demand met by solar energy

Step	Item	Example value
1	Latitude (degrees)	42.4
2	Minimum acceptable water temperature, °F (usual range, 110-160°)	140
3	Supply water temperature, °F	51
4	Gallons hot water used per day, (gal)	72
5	Area of collector, ft^2	50
6	Tilt angle of collector from horizontal, degrees	42.4

On the average, a family uses 15-25 gal of hot water per person per day. Assuming 18 gal per member per day, a family of four would require 72 gal daily.

[6]For a complete description and listing of this program see Steve Waslawski, Claudia Myers, and Bill Stout. *A Programmer's Guide for Solar Water Heating Using a Programmable Calculator*, Michigan State University AEIS No. 413, (1980).

[7]Steve Waslawski, Claudia Myers, and Bill Stout. *Solar water-heating analysis using a programmable calculator*, Michigan State University AEIS No. 414; Claudia Myers and Bill Stout. "Home hot water heating with solar energy," Michigan State University Energy Fact Sheet E-1151, (1978).

The tilt angle (Item 6) of the collector from horizontal is usually equal to the latitude ±15°. However, a tilt angle much less than 45° could result in snow buildup on the collector in cold climates.

$C_{s,a}$ = annual cost of solar/auxiliary heating system $/yr

c = constant, 1.0, yr

Table 6. Percentage of water heating demands met by solar energy

Step	Item	Example output
1	Initialize	0
2	Clearness index, fraction of diffuse radiation, insulation on tilted surface, percentage of hot water heating needs met by solar energy during January	28
3	Percentage of February's hot water demand	40
4	March's	47
5	April's	56
6	May's	61
7	June's	65
8	July's	67
9	August's	65
10	September's	58
11	October's	51
12	November's	33
13	December's	22
14	Total yearly percentage of water heating demand met by solar energy	49

Table 7 illustrates the data required for the cost analysis, and Table 8 shows the total net savings of the solar system and the approximate payback period.

Table 7. Data required for cost analysis of a solar water heating system

Step	Item	Example output
1	Annual loan interest rate, %/yr	12
2	Term of loan, years	3
3	Total cost of system, $	2500
4	Down payment, $	600
5	General inflation rate, %/yr	10
6	Fuel escalation rate, %/yr	10
7	Discount rate %, after tax return on best alternative investment	09
8	Daily water-heating load, Btu	53379
9	Yearly fraction of hot water-heating needs met by solar energy, %/yr	49
10	Present cost of conventional system fuel, $/million Btu (see Table 5)	15
11	Efficiency of conventional system furnace (see Table 5), %	1
12	Federal income tax bracket, % (available from the instruction booklet in Tax form 1040)	.35
13	Commonly used extra insurance and maintenance cost value, % of investment	.01
14	Life of system, years	20
15	Michigan and federal tax credits, $	1275

Table 8. Results of solar water heating cost analysis

Step	Item	Example output
1	Fuel savings associated with the system minus expenses over life of system	2868
2	Total net savings over life of system, $	1418
3	Payback period, years	10

Discussion[8]

Currently, the absence of a sufficiently developed market is inhibiting the growth of solar-energy manufacturing and the widespread use of solar-energy conversion systems. The reasons are primarily economic. Fossil and other conventional energy sources are still lower in cost than solar energy. Despite lack of acceptance among American energy consumers for large-scale use of solar energy, experts repeatedly emphasize the importance of beginning a partial switch to solar energy based on objective studies and evidence of steadily rising costs for conventional energy. Every energy projection hypothesizes substantial contributions by solar sources to the national energy requirement by the year 2000. The president's July 1979 energy message emphasized a national goal of 20% of the country's energy needs from solar technologies by the end of the twentieth century. Reaching this goal demands a veritable upheaval in current manufacturing practices.

A continuation of present trends would mean falling substantially short of this goal. To meet even the most modest objective for a solar contribution to the national energy requirement by the year 2000, mass production methods must be introduced without delay.

Considering the present state of solar energy use, scant progress has been made toward achieving substantial energy contributions from solar sources. Current solar collector production is only a meager fraction of the projected need. In 1978, collector production (mostly low temperature, nonmetallic units) was about 11 million ft^2. Thus, meeting the year 2000 goal requires multiplying solar collector production by a factor of 25+ annually.

[8]A more detailed discussion of the need to accelerate commercialization of solar energy applications is by J. A. Clark, et al. and the Central Solar Energy Research Corporation, *Solar manufacturing technology assessment.* Final Report No. 795. Prepared for the Solar Energy Research Institute and the Department of Energy, Division of Conservation and Solar Energy (1978).

PHOTOVOLTAIC TECHNOLOGY[9]

Introduction

Generating electricity directly from the sun depends on the photovoltaic (PV) effect. This process occurs when light hits certain sensitive materials and creates an electron flow, or electric current. The basic units that accomplish this are called solar cells. The first practical solar cells were maufactured in the mid 1950s and were used to power remote weather equipment. The most familiar applications are in photography, where they are used in light meters, and in the space program, where they have provided electricity for space vehicles.

Photovoltaic technology provides an inexhaustible and relatively nonpolluting energy source. The technical feasibility has existed for years, but the current cost of systems has confined their use to small-scale, remote applications. To achieve significant fuel displacement, PV systems must competitively replace the electric energy supplied by utility grids.

Photovoltaics could displace anywhere from 0.1 quad to more than 1 quad of primary energy annually by the year 2000. The actual amount would depend on cost-reducing technological advances, the extent that the government stimulates the adoption of solar energy, and external events such as oil price increases.

Overview of the Technology

Solar electricity from photovoltaic conversion

Solar cells. A typical solar cell contains two very thin layers of silicon with an outside wire attached. In one layer, a few atoms in the silicon crystal have been replaced by boron atoms; in the other, the replacement atoms are phosphorus (Fig. 9). Sunlight falling on the cell forces electrons to move along the wire from the phosphorus-silicon layer to the boron-silicon layer. Theoretically, silicon solar cell should be able to convert about 25% of the sun's energy into electricity. In practice, 16% is the highest conversion achieved to date for mass-produced solar cells.

Solar cells are expensive because their fabrication requires handcrafting. A single crystal of pure silicon is articially grown in ingot form; wafers cut from the ingot are polished and trimmed; the impurities are diffused into the silicon in an oven; electrical connections are added; and the finished cells are mounted in arrays. Prices for growing crystals and slicing the silicon into 15-mil thick circular cells are \$200–400/m^2.

Solar modules. Solar cells can be connected electrically to form solar modules, the basic building blocks of solar electric systems. For example, 40 cells connected together will charge a 12-volt (V) automobile battery. Different modules are available from companies manufacturing solar electric products. In 1979, enough silicon modules were produced to generate about 1 MW of electric power.

The module alone does not provide a PV power generation system. In addition to modules, a PV system includes mounting frames, frame supports, foundations, electrical wiring, control and load-management circuits, power conditioning, energy storage, and maintenance equipment. Called balance-of-system (BOS) elements, these items are

[9] Adapted from DOE Office of Public Affairs, "Solar electricity from photovoltaic conversion."

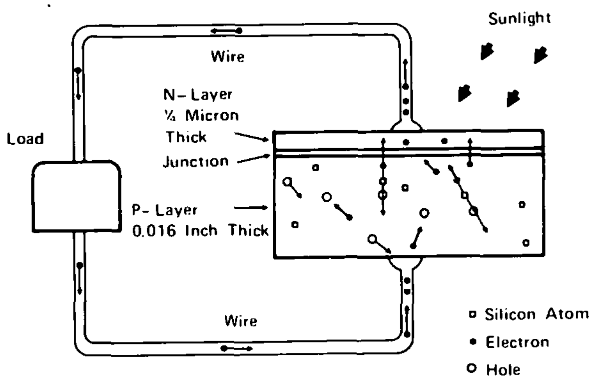

Fig. 9. A silicon solar cell. The cell has a thin *n* layer (phosphorus-silicon) and a *p* layer (boron-silicon). When sunlight delivers energy to the *p* layer, electrons are knocked out of some of the silicon atoms, leaving "holes" in the electron structure. These free and energetic electrons move across the junction to the *n* layer and then through the wire load, where their energy is converted to useful work. The electrons then go to the *p* layer and reenter its electron structure at the holes. Source: DOE Office of Public Affairs, "Solar Electricity from Photovoltaic Conversion."

normally purchased from another company by the module manufacturer. Module manufacturers will gradually reduce costs by fabricating or assembling BOS elements in their factories as part of the PV system package.

Power systems. Any power output can be supplied by combining modules into a solar array. A regulator is needed to control the voltage and to direct it to a storage battery, if required. Since solar cells generate direct current (dc) electricity, a power conditioner is needed to convert it to alternating current (ac) power to make solar electricity compatible with the existing distribution system in the United States.

Many factors must be considered in designing an array for a reliable solar power system. The total number of hours of sun as well as seasonal changes in the sun's angle must be determined. Average weather conditions and local terrain must also be considered. A solar array is rated in peak power, which is the wattage it delivers at noon on a clear day.

Solar arrays have been fabricated for a variety of applications requiring modest power. Solar arrays provide 50 W to power U.S. Coast Guard buoys in Long Island Sound. The U.S. Forest Service employs a 16-W array to power a voice-radio repeater atop White Mountain in California. A 1.7-W array operates a backpack-mounted two-way radio carried by Forest Service guards patrolling mountain trails in Inyo National Forest in California.

Prior to the DOE program, the largest solar array ever built was the 10,000-W unit that powered the Skylab space station put into orbit in 1973. Recent DOE experiments include a 3.5-kW PV plant for an Indian village, a 25-kW irrigation experiment, a 15-kW PV system for a radio station, and a 60-kW plant for an Air Force radar station.

Solar cells may soon generate economical electricity for homes or buildings. A 20- by 30-ft panel of solar cells, operating at 10% efficiency and 5000 peak W(p) at midday in the northeastern United States, would yield an average of at least 1000 W annually—more than enough to meet the electricity needs of an average house. For larger houses, the area of the panels could be correspondingly increased. However, it will probably not be economically attractive to store electricity on a large scale to provide power during periods of darkness or when power demand exceeds solar-cell capacity. Consequently, a backup source of electricity would be needed.

In addition to PV conversion alone, DOE is studying ways of combining PV conversion with other methods of using solar energy. One approach involves concentrating the sun's rays onto solar cells with mirrors or lenses. This may boost the power of an individual solar cell by a factor of 50 or more. Another approach is a combination heat-PV solar collector that could provide heat, cooling, and electricity for an individual home. This combination might use as much as 60% of the solar energy reaching the collector.

Advanced material research and technology

Flat-plate silicon collectors and a variety of concentrating and total-energy collectors have already demonstrated their technical feasibility. Flat-plate silicon collectors are produced commercially at a rate of about 1MW(p)/year.

Much progress has been made in developing PV concentrator technology. Concentrator systems offer somewhat higher collector conversion efficiencies than those attainable by low-cost flat-plate technologies. Moreover, they can produce thermal energy at temperatures higher than are attainable with flat-plate collectors. Single-crystal silicon cells have achieved 18.5% conversion efficiency at 40–60 suns' illumination; gallium arsenide cell combinations operated in a split solar spectrum mode have achieved 28.5% efficiency. Advanced devices such as multiple-junction compound semiconductor cells are likely to achieve conversion efficiencies in the 30–40% range within five years.

The potential exists for achieving $0.15–0.40/W(p) collectors, which should allow system costs of $1.30/W(p) or less. This will make central utility applications viable.

Manufacturing technology

The most significant cost item for the PV device is the basic raw material, polycrystalline silicon. Although it is not yet worthwhile for manufacturers to produce their own **solar grade** polycrystalline silicon, applying automation techniques would probably enable those using labor-intensive assembly sequences to reduce costs up to 40%. Costs of the most advanced manufacturing operations might be reduced another 10–15% by automation.

An Economic Assessment of Photovoltaic Systems[10]

In 1979, solar cell modules suitable for use on land were priced at 6–12/W(p). Thus a 20- by 30-ft panel of solar cells would cost $40,000–80,000. While initial costs are high, operating costs for solar electric systems are relatively low.

For remote applications of 10–100 W, PV systems are already economically competitive. The range in the cost of those presently marketed is $20–50/W(p), including the array, storage batteries, regulators, and power conditioners. Large-scale applications will require much lower prices. In 1980 dollars per peak watt, module price goals are

[10] Based on Paul D. Maycock, "Overview — Cost Goals in the LSA Project," DOE; DOE Division of Solar Technology, *National Photovoltaic Program Plan*, DOE/ET-0035(78); and John Clark *et al.* and Central Solar Energy Research Corp., *Solar Manufacturing Technology Assessment — Photovoltaic Conversion Systems. Final Report No. 795*, prepared for the Solar Energy Research Institute and the U.S. Department of Energy, Division of Conservation and Solar Energy (1979).

$2.80 and $0.70 by 1982 and 1986, respectively (Table 9). The corresponding goal for commercial readiness of systems is $1.60-2.20/W(p) in 1986 for both residential and intermediate load center applications.

The prices of PV systems and arrays as determined by fixed-price bids have been coming down since the federal program began in 1974 and price goals were formally instituted (Fig. 10). The next level of price reductions, the 1982 goals, appears within reach if markets develop to bring in the risk capital needed. The 1986 goals are more difficult and risky and will require new manufacturing technology.

Table 9. Photovoltaic module, system, and energy price goals in 1980 constant dollars

Year	Module prices (FOB) $/Wp	System prices $/W	Energy prices[a] ¢/kWh	Prime application
1982	2.80	6-13	5.2-8.7	Remote international
1986	0.70	1.60-2.20	5.5-9.2	Residences
1990-2000	0.15-0.40	1.10-1.30	4.2-8.1	Utilities

[a] Based on the selling back of excess power to the utility at 50% of the charge rate to the customer.

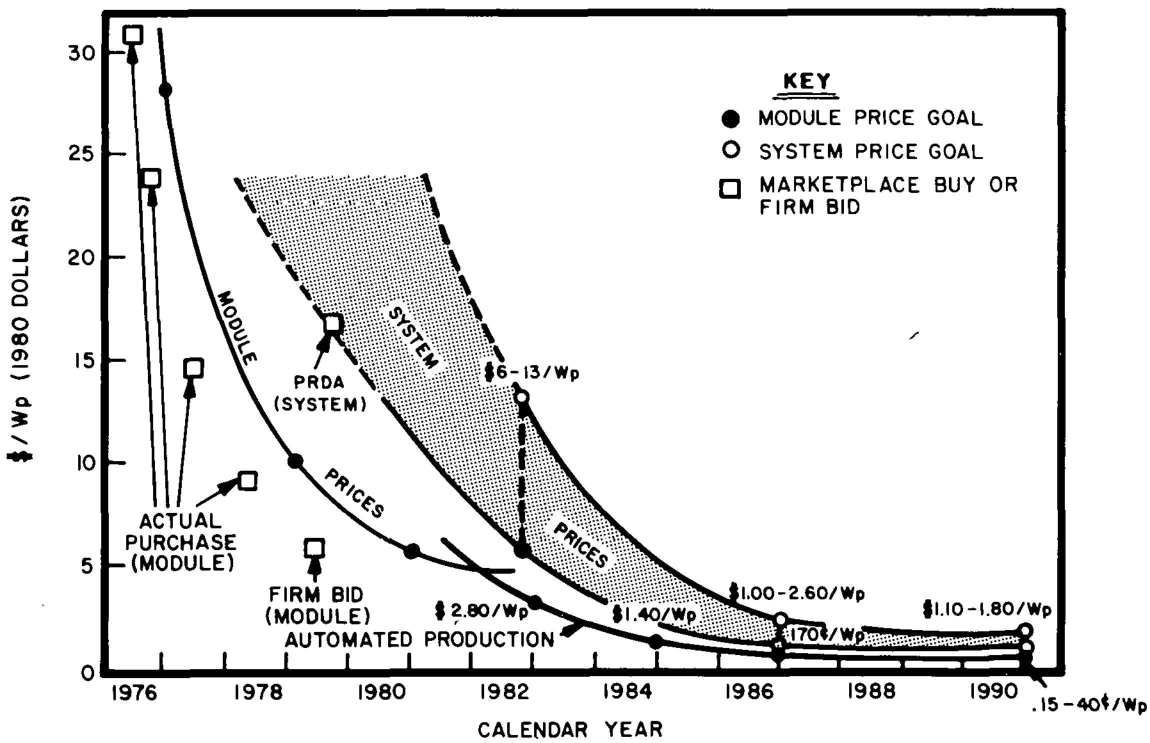

Fig. 10. Photovoltaic module and system price goals. Source: Paul D. Maycock, and Leonard M. Magid. "The U.S. National Photovoltaic Program," Seventh Energy Technology Conference, DOE Division of Photovoltaic Energy Systems (1979).

Photovoltaic systems include not only hardware components but everything in the chain from materials through applications, including marketing and distribution, installation, and operation and maintenance. This concept is illustrated by the residential model shown in Fig. 11. Utility rate structures, taxes, and other financial, legal, and institutional factors must be assessed for their effect on system requirements, production processes, and siting requirements.

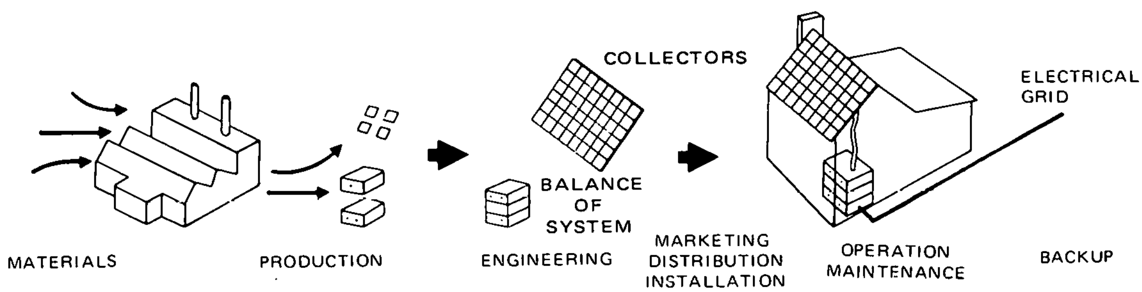

Fig. 11. A model of a residential photovoltaic system. Source: DOE Division of Solar Technology, National Photovoltaic Program Plan, DOE/ET 0035(78).

Many components are already commercially available (e.g., structural components, wiring, and lightning protection). Nevertheless, substantial cost reductions are essential to achieving overall PV system goals. Most PV system cost is devoted to control equipment and energy storage. Mechanical energy storage technology can inherently provide control and conditioning as well as energy storage, resulting in potential cost benefits over competing technologies. An additional advantage, useful in some applications, is the higher power capability of mechanical energy storage (relative to conventional batteries).

To enable selection of the optimal design for the PV cell and the array structure, a trade-off analysis is needed of how factors such as system performance, durability, reliability, and maintenance will influence the manufacturing costs and lifetime costs of mass-produced systems. For a number of substantive and technical reasons, it appears that a module price of $0.60-1.00/W(p), entailing a total installed-system price of $1.50-2.50/W(p), is the benchmark figure at which PV systems become competitive in most parts of the United States for general use. At this price solar arrays will generate electricity at a full cost to the user of 5-7¢/kWh.

Discussion

Photovoltaic systems are capable of providing electricity from the sun for a variety of applications, sized from microwatts to megawatts, virtually all over the world. Terrestrial applications since 1974 have demonstrated that reliable PV systems can be built that require only minimal maintenance. The principal barrier to massive deployment is the installed-system cost.

Photovoltaic technology is advancing rapidly, and existing problems have attainable solutions. Reducing costs sufficiently to bring PV systems in line with other energy sources is the aim as well as the challenge. The challenge is significant, but the reward of an economically viable, distributed, renewable energy option by 1986 is worth the expense.

WIND ENERGY[11]

Introduction

Environmental concerns and worldwide energy shortages have renewed interest in capturing the wind's energy and converting it to a usable form. Early in the 1970s, worldwide experimentation with wind power focused on electricity generation. However, the development of **windmills** to generate electricity and not just mechanical power is advancing a group of new machines called wind turbine generators (WTGs). Emphasis is on the generation of electricity because (1) WTGs easily and efficiently generate this high-cost, useful energy form and (2) in most modern societies an electricial distribution network exists, which allows WTGs to be interconnected to form a wind-energy conversion system (called a WECS if it is composed of large WTGs and a SWECS, for small-scale wind-electric system, if it is less than 100 kW).

Wind-energy resources for the United States

Increased interest in wind power has resulted in a number of National Wind-Energy Assessments. These reports, using National Oceanic and Atmospheric Administration weather station wind data and other historical weather records, have mapped the distribution of the total available wind power over the United States. The map in Fig. 12 identifies regions in the United States where mean wind-power densities exceed 400 W/m^2. These are (1) a region comprising parts of Texas, Kansas, Nebraska, Oklahoma, and New Mexico; (2) the offshore regions of New England and the Northwest coast; and (3) exposed mountaintops and ridges in mountainous regions in the East and West. Thus, the wind resource in New England is located offshore or in the high hills and mountains. The Great Lakes constitute another high wind region. Figure 12 indicates that the Great Lakes and their shoreline have mean wind-power densities greater than 300 W/m^2.

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[11] Based on the following works by W. T. Rose, Jes Asmussen, and Bill Stout: *A Survey of Commercially Available Wind-Electric Systems* and *Wind Energy Economics Analysis*, Michigan State University AEIS 426 (1980) and 427 (1980), respectively; and on Jes Asmussen, *Wind Energy-Its Promises and Problems*, University of New Hampshire Center for Industrial and Institutional Development (1980).

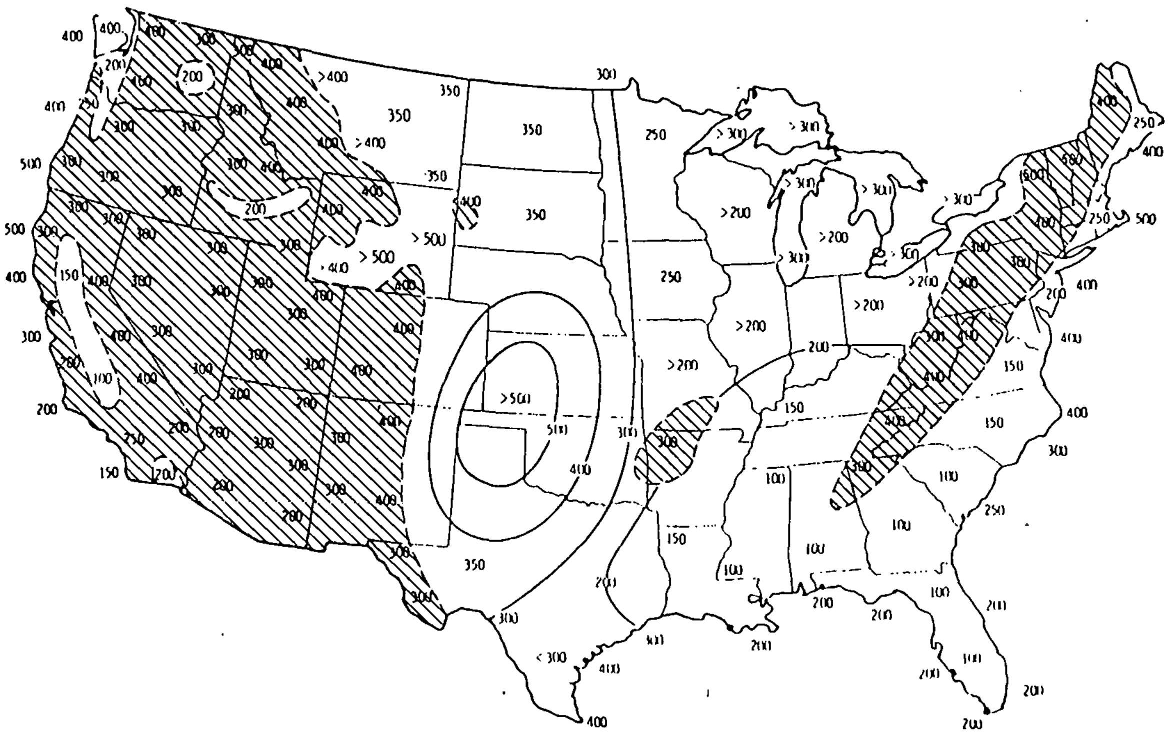

Fig. 12. Mean annual wind power (W/m^2) estimated at 50 m above exposed areas. Over mountainous regions (shaded areas), the estimates are lower limits expected for exposed mountaintops and ridges. Source: D. L. Elliot, *Synthesis of National Wind Energy Assessments*, Battelle Northwest Laboratories, BNW/Wind-5 UC-60 (July 1977).

Wind-energy potential for the United States

A recent study by Gustavson published in *Science* showed that the usable global wind-energy potential is 3900 quads per year—more than 39 times the usable global energy potential for the combined renewable resources of hydropower, geothermal heat, and tidal energy. The upper limit for the United States was estimated at two million 1-MW WTG installations before environmental effects of the machines would become important. However, other studies, accounting for economics, technology development, and the time required to implement mass production, estimate that WECSs will contribute between 0.1 and 6 quads per year by the year 2000. The most probable estimate of 1-2 quads represents 40,000-80,000 2.5-MW WTGs.

Several factors will accelerate WTG technology toward these predictions, including (1) the need to increase energy-generation capacity by any means in order to satisfy a healthy, full-employment economy; (2) operation of WTGs in parallel with utility grids to act as fuel savers—one quad of WTG electricity saves three quads of oil, or $10 billion [at $20/barrel (bbl)]; (3) public dissatisfication with nuclear power; and (4) promising WTG economics for machines of all sizes.

An Overview of Technology

Wind technology development is experiencing its most rapid growth in history. While there were only a few manufacturers in the United States in the early 1970s, there are now over 25 SWECS manufacturers, each with its own prototype WTG or WTG product line. Competition to build and to market a long-life, cost-effective WTG is intense.

Large wind-electric systems

Until mid 1978, the Smith-Putnam Project, resulting in 1250 kW, was the largest WTG constructed. This 175-ft diameter utility-interconnected WTG was built on a hill called Grandpa's Knob in central Vermont. The project was abandoned in November 1945 because a study showed that wind power was not economical for the Central Vermont Public Service Company. It was generally agreed, however, that the Smith-Putnam WTG was a technical success.

The DOE Large-WTG Program (1979). The Lewis Research Center of the National Aeronautics and Space Administration (NASA) at Cleveland is managing the DOE large-WTG program. Part of its effort is devoted to the design, prototype development, and demonstration of a series of large (>100kW) utility-interconnected WTGs. Four basic machines have been developed:

1. *MOD-0.* This first DOE-NASA design is a downwind, constant-rpm machine capable of producing 100 kW in an 18-mph wind. Situated on top of a 100-ft tower in Sandusky, Ohio, the generator is rotated by a blade assembly measuring 125 ft in diameter (diam). Useful power can be generated in winds of about 8 mph, and full output can be attained from 18-35 mph wind. No energy can be produced above 35 mph because the blades must be **feathered** (turned out of the wind) to prevent damage to the machine.

Installed in the fall of 1975, this machine was the first large WTG built by DOE and is presently used for research. It has proved to be a valuable engineering instrument for evaluating advanced design concepts. Several different design factors are being examined, including tower stiffness; blade shape; and materials; upwind versus downwind positioning; and generator types, utility interconnection, and system control.

2. *MOD-0A.* Four MOD-0A systems will be built by Westinghouse Electric Corporation. The first, installed in March 1978, is located at Clayton, New Mexico. Tied into the town's electrical network, it has operated successfully for over two years. By the end of May 1978, the machine had completed 1000 hr of operation and had generated over 100,000 kWh. It works with seven diesel generators and can supply 15% of Clayton's total power during off-peak periods.

The second and third machines are located at Culebra, Puerto Rico, and Block Island, Rhode Island. A fourth MOD—0A is being installed on the island of Oahu for the Hawaiian Electric Company. These wind generators resemble the MOD-0 unit but require a 200-kW electrical generator. They have demonstrated the technical feasibility of wind turbines in utility applications.

3. *MOD-1.* The MOD-1 WTG was designed for high-wind regimes. It is a 2-MW, two-blade, horizontal-axis experimental machine optimized for a site having wind that averages 18 mph (at 30 ft). The 200-ft diam WTG was developed to determine the economic

and operating characteristics of a utility-operated megawatt-scale system. General Electric Company is the prime contractor for designing, fabricating, and installing the MOD-1. However, Boeing Company of Seattle, Washington, manufactured thc two steel blades. A single prototype was installed in Boone, North Carolina, in 1979.

4. *MOD-2.* This 300-ft-diam, 2.5-MW WTG is designed for a site with lower (14-mph) average wind than is the MOD-1 WTG. This WTG design should provide a cost-competitive megawatt-size machine for moderate-wind sites over large regions of the United States. Levelized costs of less than 4¢/kWh in average-wind regimes (12 mph or more) are projected.

The design of this machine has been greatly influenced by the new technology derived from the MOD-0, MOD-0A and MOD-1 experiences. Two important new design concepts are (1) a soft (flexible) welded-steel, cylindrical-shell tower and (2) partial-span pitch control and teetering rotor. These adjustments allow for lighter overall weight and resultant cost reductions. Boeing is the prime contractor; DOE plans to install three prototype units together as a 7.5-MW WTG farm near the Oregon-Washington border during 1980-1981.

U.S. private and foreign large-WTG designs. Significant projects are summarized below; they illustrate the large diversity that exists at a number of different levels.

1. *WTG Energy Systems 200-kW WTG.* WTG Energy Systems, Inc., of Angola, New York, recently introduced its 200-kW WTG, which has logged over 1000 hr of electrical generation on Cuttyhawk Island, Massachusetts, since July 1977. This unit, designated as Model MPI-200, was designed using some concepts from the Danish Gedser WTG and is built from off-the-shelf components whenever possible. It is an 80-ft diam, three-blade upwind machine that supplies 60-hertz (Hz) power to a local utility in 8-mph winds and achieves a rated output of 200 kW at wind speeds of 30 mph. Shutdown occurs at wind speeds of 60 mph; the unit is designed to survive 150-mph winds. Plans call for the installation of several more of these machines in the United States and Canada during the next several years.

2. *Schachle.* Patrick J. Schachle, a private developer from Moses Lake, Washington, has been operating a three-blade, 72-ft diam, 140-kW upwind WTG since May 1977. This machine supplies utility-grid electricity to the Grant Company (Washington) Public Utility District. The Schachle system features an orienting scheme which rotates the entire tower to align the blades with the wind flow and also a method of transmitting the blade power to the generator through a hydraulic system.

In mid 1978, Southern California Edison (SCE) contracted for a 165-ft-diam Schachle wind generator capable of producing 3 MW in a 40-mph wind. The unit is under construction near Palm Springs, California, and is expected to produce about 6 million kWh/yr-enough electricity for 800-1000 residential customers. This wind-turbine-generated electricity is expected to save about 10,000 bbl of oil per year. If this prototype demonstration proves successful, SCE expects to purchase and to install many large WTGs on its utility network. Bendix Corporation recently purchased the rights to build and to market Schachle WTGs.

3. *Energy Development Company WTG.* Energy Development Company of Hamburg, Pennsylvania, has developed a series of four-blade, downwind, fixed-pitch WTGs. These machines were designed by Terrance Mehrkam, owner and president of the company, which offers four standard, four-blade models rated at 40, 45, 100, and 225 kW. These

medium-sized WTGs can power several households, a farm, or an industrial or commercial operation, yet their costs are within reach of individuals or businesses that can benefit from the dispersed wind resource.

4. *DAF WTG.* Dominion Aluminum Fabricating (DAF), Ltd., in Mississauga, Ontario, Canada has been developing vertical-axis wind turbines (of the Darrieus design) under contract with the National Research Council of Canada. An 80-ft-diam Darrieus WTG was installed on Isle Magdaline, Quebec, in the Gulf of St. Lawrence. Output of this machine was about 220 kW.

The firm has three 55-ft Darrieus WTGs operating at remote sites around Canada and is building more. DAF claims that wind turbines of this size and larger, when placed in remote, windy locations, can be economically competitive with diesel or other fuels.

5. *ALCOA WTG.* Aluminum Company of America (ALCOA) is gearing up to produce an introductory line of vertical-axis wind turbines in sizes of 8, 26, 55, 114, 280, and 500-kW. According to ALCOA, electrical power will be produced for 4-6¢/kWh based on 15-mph average wind speeds and an 18% annual fixed charge rate.

A three-blade, utility-interconnected, 500kW Darrieus turbine will be erected on the Oregon coast for Eugene Water and Electric Board, at an installed cost of $250,000. A minimum average wind speed of 12 mph is needed to start the turbine which reaches maximum output in a 35-mph wind. Standing 123 ft high, it will be the largest vertical-axis wind turbine in the United States and is expected to generate 1.1 million kWh each year (in winds averaging in excess of 14 mph for the year), enough energy to meet the annual needs of over 100 residential customers.

6. *Danish Tvind and other foreign WTGs.* Sweden, Germany, France, Holland, and Denmark have initiated wind-electric research programs. In Sweden, the Saab-Scania Aerospace Division has built a 75-kW, 59-ft-diam, two blade WTG. This experimental machine supplied energy to the Swedish power network for the first time on April 28, 1977. The minicomputer control system starts the machine in 11-mph winds, and the generator reaches its rated power in 22-mph winds.

In Denmark, with DOE help, a new Gedser WTG has been built and is being tested. However, the most notable WTG experiment is being conducted by a private group. The Tvind Schools, near Ulfborg in West Jutland, have designed and built and are testing the world's largest WTG (until the MOD-1 is complete). Staff and students designed, built, and installed a huge, three-blade, 2-MW WTG for $650,000 in 1977.

The downwind propeller has a diameter of over 170 ft, and the tip of an upright blade stands higher than the roof of a 20-story building. The blades are constructed of fiberglass and plastic foam and weigh 5 tons each. The machine is expected to supply all the energy needs of the school, both electricity and heat, and to generate surplus electricity for sale to the local power company.

Small wind-electric systems

Small-scale wind-electric systems (less than 100 kW) are suitable for a home, farm, or small business. From 1920 to 1940, small wind-electric systems were highly developed and were produced in large numbers in the United States. Two well known examples of these machines are the Jacobs WTG and the Windcharger WTG. Both of these produced direct-current electricity for isolated and rural battery-charging applications.

Thousands of Jacobs WTGs were installed in the rural United States and in the world between 1931 and 1957. These machines were built for low maintenance and thus used direct-drive, low-rpm electrical generators of 2.5-3 kW. A 15-ft diam propeller produced at least 400-500 kWh/mo in most areas in the western United States. The Jacobs WTG is no longer manufactured, but during the last several years, over 200 old Jacobs WTGs have been reconditioned and placed back in useful operation.

The windcharger, built for small electrical loads, has a rated power of 200 W. This WTG is still manufactured in the United States in quantities in excess of 2000 units per year. Most of these WTGs are exported. Designed primarily to replace or to supplement utility-supplied electricity, SWECS have become increasingly popular. Over 100 different models are available from 30 manufacturers in the United States.

Rocky Flats small wind systems program. During 1976, as part of the federal wind-energy program. DOE authorized establishment of the Rocky Flats wind systems program. The goal of this program is to facilitate the testing, development, and commercialization of SWECSs designed for farm, home, and rural uses. Two major components of this program are (1) to establish a national facility where small wind systems are tested, in order to assess the current state of the art and to identify required technology improvements and (2) to subcontract research and development aimed toward reducing the cost and improving the reliability of SWECSs. Five advanced SWECS projects, from 1 to 40 kW in size, are under way. Applications for each of these are as follows:

1. *One to two-kW* (high reliability) systems. Designed for rural and remote needs, such as powering repeater stations, seismic monitors, offshore navigation and water pumping at remote sites.
2. *Four and eight-kW systems.* These are designed to supply power to homes and farm buildings.
3. *Fourteen-kW systems.* These are designed for single family residences with space heating and for farm and small commercial applications.
4. *Forty-kW systems.* These are designed for deep-well irrigation systems and electrical power for small, isolated communities and factories.

The design specifications for the 1-kW to 2-kW, 8-kW, and 40-kW machines are summarized in Table 10. They represent the variety of approaches that is typical of a new industry (since optimum WTG designs have not yet been established). Three vertical-axis concepts are represented: a 1-kW cycloturbine, a 1-kW Darrieus, and a 40-kW gyromill. (Two and three-blade downwind and upwind horizontal-axis WTGs are being developed with different feathering concepts.)

As part of the Rocky Flats program, United Technologies Research Center is developing SWECS designs that employ a new blade-pitch control system, called the composite bearingless rotor (CBR). This new idea eliminates a mechanical pitch control and shows promises of allowing WTG simplicity and low maintenance. Blade-pitch control is achieved by applying a movement with a pendulum at the outboard end of the blade's inboard section and elastically twisting the section.

In addition to the SWECS testing and design programs, Rocky Flats has initiated a SWECS demonstration program in which over 100 WTGS will be purchased from qualifying manufacturers and will be placed in applications throughout the United States. This will provide a way of field-testing and demonstrating machines under many different conditions.

Table 10. Specification of advanced SWECSs under development

Contractor	Output (kW) at 20 mph	Configuration	Rotor size	WTG weight (lb)	Tower weight (lb)	Contract amount ($)
		1-2-kW (high reliability) systems				
Enertech	2.3	2-blade horizontal axis, downwind	16.4 ft dia.	350	300	150,000
North Wind	2.0	3-blade horizontal axis, upwind	16.4 ft dia.	325	300	260,000
Aerospace Systems Inc.	1	3-blade vertical-axis cycloturbine	15 ft dia. × 8 ft high	508		280,000
		8-kW systems				
Windworks	8	3-blade horizontal axis, downwind	31 ft dia.	1,600	2,362	388,000
United Technologies Research Center	9	2-blade horizontal axis, downwind	31 ft dia.	1,855	2,619	438,000
Alcoa	11	3-blade vertical-axis Darrieus	33 × 34 ft	10,480		356,000
Grumman	11	3-blade horizontal axis, downwind	33.25 ft dia.	2,540		356,000
		40-kW systems				
Kaman Aerospace Corporation	40	2-blade horizontal axis, downwind	64 ft dia.	4,900	4,000	
McDonnell Aircraft Corporation	40	3-blade vertical-axis gyromill	32.5 ft × 65 ft			

Source: Jes Asmussen. Wind Power—Its Promises and Problems, University of New Hampshire Center for Industrial and Institutional Development (1980).

U.S. Department of Agriculture wind program. Economic feasibility studies are being performed for such rural wind-power applications as deep- and shallow-well irrigation, farm building heating, crop drying, refrigeration, cooling and water-heating systems, and agricultural product processing and storage.

Studies show that these applications are technically feasible. The program has several WTG farm demonstration projects, including (1) a 56-kW Darrieus WTG for irrigation; (2) low-lift pumping directly coupled to a WTG; (3) wind-powered cooling of dairy milk; and (4) wind-powered refrigeration of an apple storage warehouse.

Sandia. Sandia National Laboratories in Albuquerque, New Mexico, is testing Darrieus machines 6, 15, and 55 ft in diameter. The largest machine produces about 30 kW, the middle one about 3-5 kW.

A recent DOE assessment has shown the Sandia vertical-axis wind generators to be economically competitive with horizontal-axis machines. Buoyed by this report, Sandia hopes to expand its program and to develop Darrieus systems capable of megawatt power production.

The systems and applications

Generally, wind energy can be converted to (1) mechanical energy; (2) heat, or thermal energy; and (3) electrical energy. Although electricity is a more costly energy form than the other two, it is more easily transported and used. Thus, economics usually favor electricity generation. Applications of WTGs to direct mechanical water pumping and irrigation are also expected to increase substantially as fossil fuel costs rise. However, while the number of these machines is expected to increase in the next 10-20 years, the major application of WECSs and SWECSs will be wind-electric systems.

WTG classifications. Wind turbine generators are classified as either horizontal- or vertical-axis machines (Figs. 13 and 14). The familiar horizontal-axis WTG receives greater attention in the development of economical small-scale wind-electric systems. The rotor shaft is located in the horizontal plane, while the blades sweep an area in the vertical plane. Horizontal-axis machines pivot freely on the tower to remain oriented into the wind. Upwind and downwind designs are available. A WTG with a tail is an upwind design (Fig. 13*b*); a downwind WTG has its rotor downwind of the tailless body (Fig. 13*c*). Horizontal-axis WTGs should be placed on tall towers (50-70 ft in Michigan) to **catch** the increased wind energy above the ground.

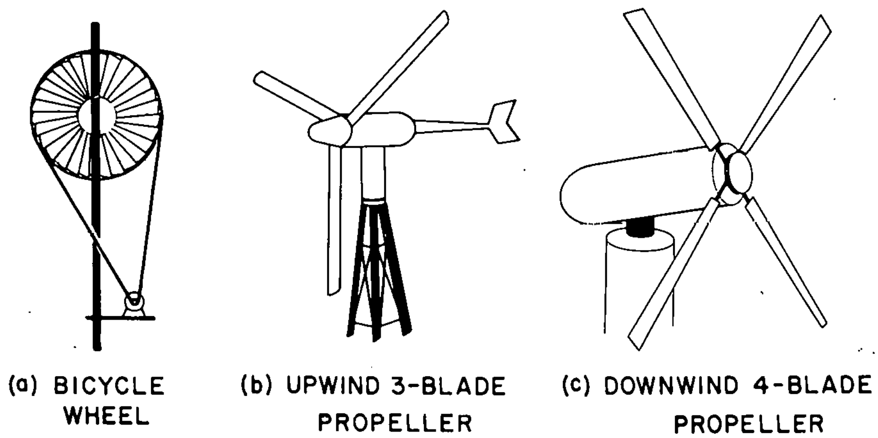

Fig. 13. Three horizontal-axis WTGs. Source: W. T. Rose, Jes Asmussen, and Bill Stout, *A Survey of Commercially Available Wind-Electric Systems,* Michigan State University AEIS 426 (1980).

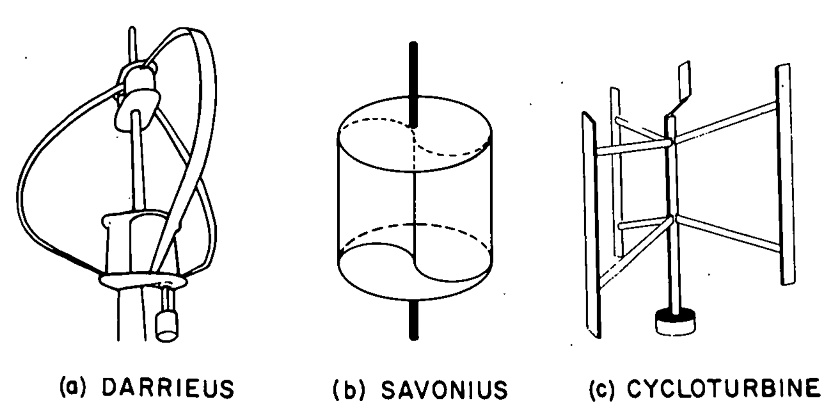

Fig. 14. Three vertical-axis WTGs. Source: W. T. Rose, Jes Asmussen, and Bill Stout, *A Survey of Commercially Available Wind-Electric Systems,* Michigan State University AEIS 426 (1980).

Vertical-axis WTGs are not placed on tall towers and are always oriented into the wind. Since winds from any direction work well, vertical-axis may be preferable in areas where wind patterns shift rapidly. Vertical-axis WTGs are sometimes used to supply mechanical power, since the rotating shaft is easily extended to ground level. These WTGs are not as efficient per swept area as the horizontal-axis machines.

The vertical-axis WTGs with the most wind-electric potential are the Darrieus and the cyclogyro and gyromill. The Darrieus WTG, named after its French inventor, has two or three curved blades attached to a vertical shaft and does not require a variable-pitch mechanism to protect it from high winds. A starter is required to bring the machine up to the proper operating speed. Often, the generator doubles as the starter. The cyclogyro and the gyromill have straight, variable-pitch blades in place of the curved blades of the Darrieus. The straight blades cost less to manufacture and make the machine self-starting. In addition, the cyclogyro operates more efficiently at low speeds than the Darrieus, which reduces the centrifugal forces and makes the WTG easier to build.

Isolated or utility-interconnected WTGs. Wind-electric systems fall into two groups: isolated and utility-interconnected (Figs. 15 and 16). Isolated systems are located in high-wind sites not served by electrical distribution networks, such as remote islands or rural communities, national parks, and tourist facilities. Generating capacity required for these applications may vary from several kilowatts to tens of megawatts. Usually, these WTGs are powered by diesel or diesel and battery systems; hence, the economics of these applications are dominated by fossil fuel costs. It is expected that WTG and diesel-generator or WTG and battery (and other storage) systems will be the economic solution for many of these applications.

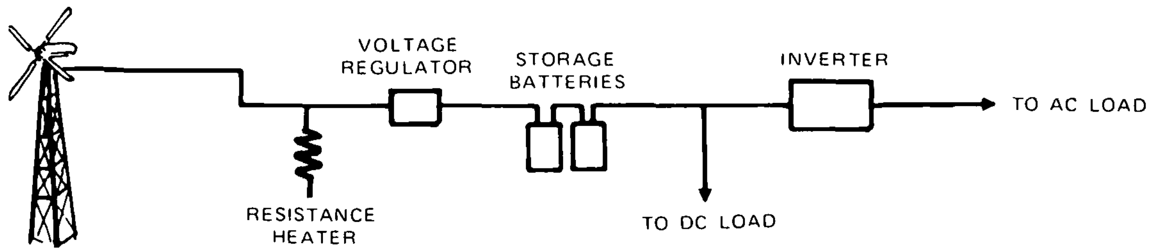

Fig. 15. A block diagram of an isolated SWECS. Source: W. T. Rose, Jes Asmussen, and Bill Stout, *A Survey of Commercially Available Wind-Electric Systems,* Michigan State University AEIS 426 (1980).

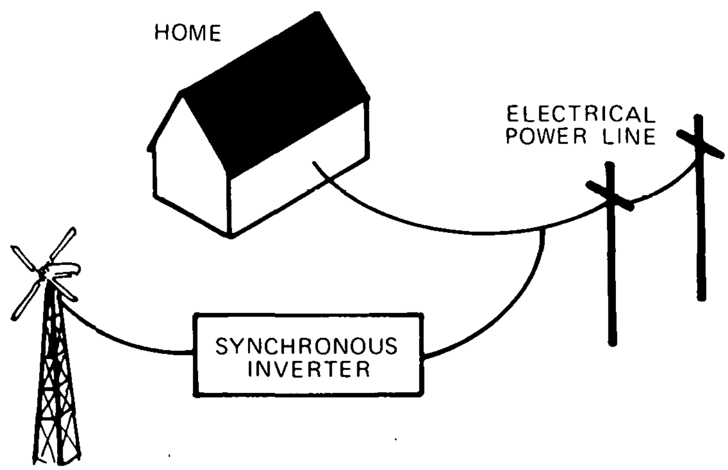

Fig. 16. One type of utility-interconnected SWECS. Source: W. T. Rose, Jes Asmussen, and Bill Stout, *A Survey of Commercially Available Wind-Electric Systems,* Michigan State University AEIS 426 (1980).

Figure 17 is a **block diagram** of four commercially available isolated SWECS. To store energy in a battery, direct current (dc) must be used and then regulated to a voltage compatible with the battery storage system design. To do this, the dc generator output is regulated (systems *A* and *B* in Fig. 17), or the ac output of an ac generator is regulated and then rectified (systems *C* and *D* in Fig. 17). (The order of regulation and rectification may be reversed in some WTGs. In system *C*, the power produced by the wind rotor is fed into an alternator that generates ac which, in turn, is rectified to dc. A regulator controls the battery-charging dc voltage, and energy is stored in the batteries and drawn off as needed. If the battery storage is full, the electric power should be diverted to some other useful application.) The direct current available from the batteries can be used directly as dc or can be inverted to ac.

Systems *E* through *G* (Fig. 18) represent utility-interconnected SWECS. They provide electricity identical in frequency and voltage to that of utility electricity; in other words, these systems must be **synchronized** with utility lines. One- or three-phase equipment is used, depending on the utility service available.

Two kinds of utility-interconnected SWECSs are available: systems having a synchronous inverter (*E* and *F* in Fig. 18) and systems having an induction generator (*G* in Fig. 18). Those with synchronous inverters are sometimes called variable-speed, constant-frequency (VSCF) systems. While the rotor rpm changes with wind speed, producing either dc or variable frequency ac, the synchronous inverter produces electrical output of constant 60 Hz frequency. Systems with induction generators are sometimes called constant-speed, constant-frequency (CSCF) systems. Due to the nature of the induction generator, the rotor speed can change no more than 5-10% regardless of wind speed.

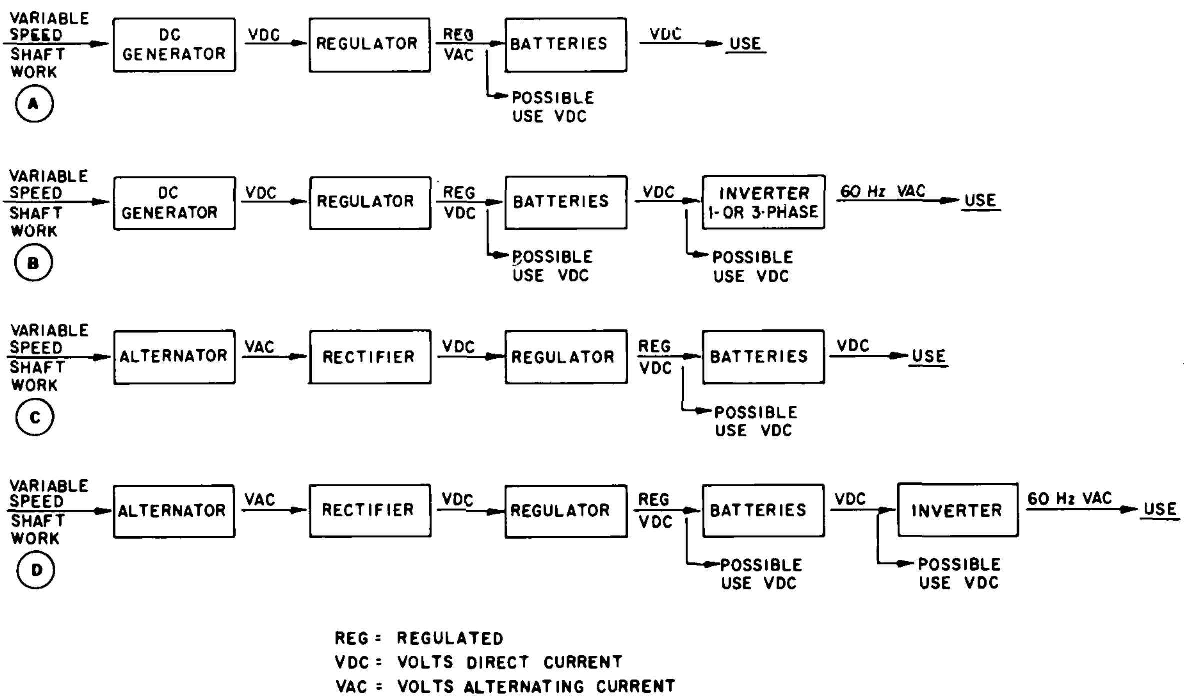

Fig. 17. Four isolated SWECSs. Source: W. T. Rose, Jes Asmussen, and Bill Stout, *A Survey of Commercially Available Wind-Electric Systems,* Michigan State University AEIS 426 (1980).

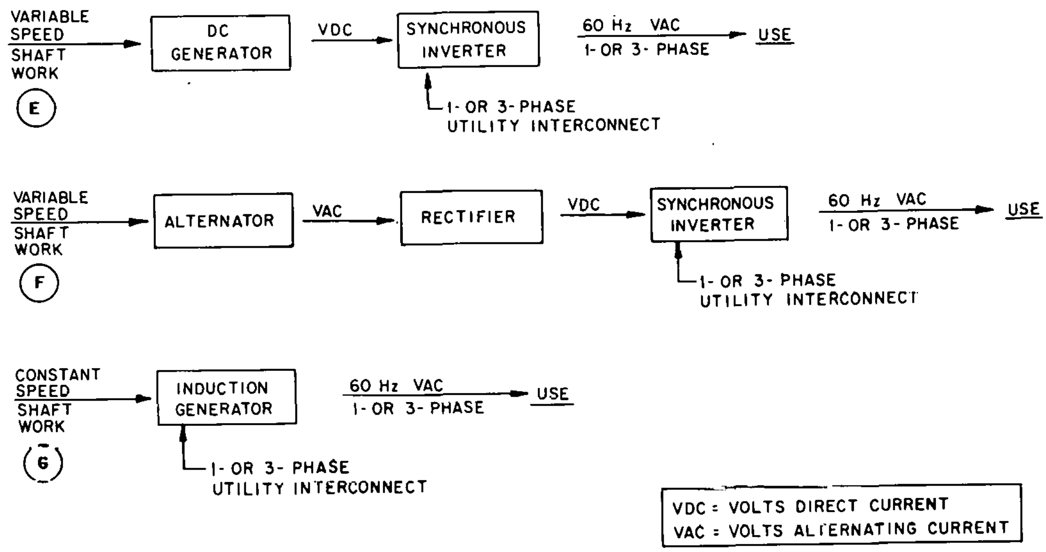

Fig. 18. Three utility-interconnected WECSs. Source: W. T. Rose, Jes Asmussen, and Bill Stout, *A Survey of Commercially Available Wind-Electric Systems,* Michigan State University AEIS 426 (1980).

Unfortunately, rotors with constant or near-constant rotational speeds cannot maintain the optimum ratio of blade tip to wind speed and thus suffer losses in aerodynamic efficiency. Therefore, the CSCF system, or induction generator, will have a larger rotor diameter than a VSCF system of similar power ratings. However, the CSCF system (*G* in Fig. 18) may cost less because it has the simplest utility interconnection and requires fewer components. At present it is not clear whether VSCF or the CSCF is the most cost effective SWECS system.

Environmental Problems

Wind turbine generators appear environmentally benign. Television interference, land use, production of low-frequency sound, and aesthetics have been identified as potential, although not serious, problems. Interference with TV reception is a problem only in the immediate vicinity of the machine and may be overcome by the installation of cable TV. Large distributed wind systems, consisting of hundreds to thousands of individual WTGs, each with its own 1 to 2-acre dedicated site and a surrounding **wind-rights** region, may pose a siting problem for utilities. Preliminary studies indicate that the public will not object to the locating of WTGs in scenic areas or close to homes.

WTG Energy Payback

For large WTGs, it takes 0.3-0.9 years (depending on the wind regime) of operation to recover the energy used to manufacture and install the machine. For small WTGs (10 kW or less), payback times may be as high as 3¼ years because of the significantly higher ratios of required concrete and steel to energy produced when the system is completed. Generally, WTG energy-payback times are low compared to those of other energy sources, and because WTGs last 20-30 years or more, the energy gain over the system's lifetime is high. During the early stages of commercialization, when WECS production is accelerating, the time required to repay the total energy used to produce the WTG will be 5-6 years after generation begins.

Summary of WTG Economics

An analysis of 1979 WTG costs indicates that **individually** built WTGs with rated powers in excess of 300 kW are currently not economically competitive even in high-wind sites. Commercially available WTGs smaller than 40 kW have economic applications if they are located at sites with average winds greater than 12 mph and if the user receives solar tax credits.

Wind turbine generators in the range of 40-250 kW in size are the **best buy** available and have proven economic feasibility (if maintenance costs are low). They can provide electricity to rural electric cooperatives and municipal utilities, large farms, and small businesses at a cost of 5-10¢/kWh at sites with average winds of 12 mph or more. Costs (in constant dollars) for **all** WTG sizes are expected to decrease further in the early 1980s as the use of mass-production techniques increases.

Technical Problems and Barriers Preventing Commercialization

While WTG technology has progressed significantly during the last seven years, problems exist that prevent rapid commercialization. The following are principle barriers.

1. *High cost.* Despite breakthroughs, the cost of most commercially available WTGs is still high.
2. *The unproven nature of the product.* WTGs have an uncertain lifetime and uncertain reliability; thus, the consumer assumes risks in purchasing commercially available WTGs.
3. *Uncertain utility rate structures.* Rate structures for non-utility-owned WTGs are uncertain.
4. *The lack of WTG standards.* Standards must be determined that both protect the consumer and provide design criteria for the manufacturer.
5. *The lack of good marketing data.*
6. *The lack of a well-developed WTG marketing and maintenance structure.*
7. *The lack of public knowledge.* The public is not familiar with wind systems, their applications, or siting problems.
8. *The lack of detailed knowledge of the wind resource.* The energy output of a WTG is very sensitive to the specific winds of the chosen site. A 1-mph difference in average wind produces a significant difference in the machines energy output.

Several of these barriers are discussed below.

WTG costs

About 500-1000 WTGs were produced in the United States in 1979. Only a few of these machines were larger than 100 kW, and most were less than 10 kW. Many smaller WTGs were copies of or were similar to the Jacobs or the Windcharger WTG. All of these WTGs were hand-assembled. Some manufacturers buy off-the-shelf components, such as electric generators and gear boxes; still, costs are dominated by low production.

The 1979 retail prices, expressed in dollars per pound (lb), for seven commercially available WTGs are given in Table 10a. As expected, the cost per pound decreases with the system's size. Comparing these costs with similar costs of mature products such as standard cars, tractors, and power shovels, indicates that costs of $2.5 -3.5/lb should be possible.

Table 10a. Cost of commercially available WTGS

System	Estimated wt (lb)	Retail price* ($)	Cost $/lb
Sencebaugh 1000 (1 kW)	810	5,425.00	6.69
Enertech 1500 (1.5 kW)	925	4,900.00	5.29
Dakota (4 kW)	1,580	7,683.00	4.86
Product Development Wind Jennie (4 kW)	1,280	6,225.00	4.86
Energy Development Co 440 (40 kW)	7,000	33,430.00	4.77
Energy Development Co 445 (45 kW)	9,500	39,300.00	4.13
WTG Energy Systems (200 kW)	85,000	310,000.00	3.64

* As of spring 1979

Thus, WTG costs may be further reduced by a factor of 1.25-2.0 by application of mass production technology. Major cost reductions beyond these must be achieved by reducing the system's weight. This will require the sophisticated use of engineering design and materials and the application of mass production technology. The installed costs (constant dollars) of WTGs of all sizes are expected to decrease in the early 1980s as more sophisticated design and manufacturing techniques evolve.

The WTG: an unproven product

The ongoing WTG tests at Rocky Flats, manufacturers' tests, and large and small prototype demonstrations by DOE and others are solving problems associated with the product's uncertain lifetime and reliability. Emphasis has been on solving problems related to blade fatigue, mechanical resonance, system stability, and highwind survival. Small WTGS purchased and placed in operation during the past several years have sometimes required onsite redesign and in almost all cases have had high maintenance costs. Despite extensive testing of small WTGs at Rocky Flats, data on utility-interconnected SWECSs is sparse.

The small amount of data available suggests that SWECSs produce less usable electric energy than the manufacturer's claim. The important questions of the amount of usable electricity SWECSs generate and the quality of this power have not been answered. Carefully planned small WTG-electric utility demonstrations are needed. These tests should identify the quantity and the quality of the electric energy generated by various commercially available WTGs. Standards should be set for power factor, harmonic content, radio frequency noise, and electrical safety for utility-interconnection schemes. The best methods to maximize the conversion of wind energy to usable electric power should be identified.

Utility rate structures for SWECSs

Most SWECS owners will use the utility service to eliminate expensive storage requirements and thereby reduce capital costs. However, the utilities must provide energy to the SWECS owners on demand but must themselves pay for the spinning reserve, distribution networks, and overhead required for this service. Utility surcharges have resulted because only one-third of the cost of electricity is due to the cost of fuel, and individual SWECSs can displace only fuel.

Utility rate structures are needed that are fair to the utility, to utility customers without WTGs, and to the WTG user. Unless long-term rate structures are determined, potential WTG buyers cannot calculate the economic potential of their application. Until this uncertainty is resolved, utility surcharges present a significant barrier to SWECS commercialization.

WTG standards

In addition to the technical performance standards required for utility interconnection, standards are also needed to protect the WTG buyer. To determine the economic benefits of owning a WTG, the potential buyer must calculate the system's life-cycle costs. This calculation involves several uncertainties: (1) the lack of detailed knowledge of the wind, (2) the speculative behavior of other competing energy alternatives over the project lifetime of the WTG, and (3) the uncertain performance of the WTG. As WTG designers and manufacturers become more knowledgeable, this uncertainty will diminish.

Manufacturers should be required (or may even volunteer) to guarantee the useful electric energy output of their WTG system in different wind regimes. This guarantee may simply specify the WTG's annual kWh output or capacity factor in different wind regimes, or it may specify the installed WTG's useful power output as a function of wind speed. In addition, manufacturers may warrant this performance over a number of years.

The definition of the wind resource

Knowledge of the macroscopic behavior of the wind is necessary for identifying regions of the country that have potential for WTG applications. However, this knowledge is not sufficient for planning WECSs, SWECSs, or even a single WTG installation. Each WTG site must be assessed for its wind-energy potential. The site's wind energy, while related to the macroscopic winds of the region, is determined by local topography, plant and other complex factors. Detailed wind measurements using special equipment are costly and time consuming. In fact, detailed measurements may cost more than a small WTG installation.

A quick, cheap method to determine accurately a site's wind-energy potential is needed, particularly in the **moderate** 10-12 mph wind regimes in the United States. These regions have the largest number of potential users, but the economics are the most speculative. A difference between an 11- and a 12-mph average wind will make a 15-25% difference in the annual energy output of most WTGs. Thus, accurate assessments of site wind are required for firm economic planning.

Discussion

Machines that capture the wind take many forms. Any device that the wind can cause to rotate, oscillate, or translate can generate electricity, run pumps, compress air or do other work. The important question is how much power can be extracted from a given wind and for how much money. The ratio of total installed cost (IC) to annual kWh output [i.e. IC/akWh] expresses this relative cost as a number. The machines with the best economic potential are those with the lowest IC/akWh ratio. Commercially available SWECSs can be evaluated by computing this number. Technical feasibility for both SWECSs and

WECSs was demonstrated during the period of 1920-1960. Both SWECSs and WECSs have few environmental problems, and some commercially available WTGs (20-250 kW) are suitable for numerous applications even at sites with average winds of 12-mph. Development of mass-produced WTGs may further reduce costs by 25-50%. Studies for large WTGs point to future economic feasibility if production exceeds 100 units per year. The DOE MOD-2, the Schachle-Bendix WTG, and the ALCOA Darrieus WTG could demonstrate that large WTGs will be economically feasible in the near future.

Thus large numbers of SWECSs and WECSs may provide the United States with 1-2 quads of economically competitive electricity by the year 2000. Wind-turbine generators displace increasingly expensive fossil fuels, and where hydro storage is available, their economic value of utilities is further increased. Because of the statistical availability of the dispersed wind source, utility-plant requirements may be reduced .

In view of these and other potential benefits, SWECSs and WECSs should be rapidly commercialized. The well-managed DOE wind energy program plans to commercialize small and large WTG technologies. However, more private initiative, especially from the principal benefactors of WTG applications, is necessary.

AGRICULTURAL BIOMASS FOR FUELS[12]

Introduction

Biomass includes everything that grows — all organic matter except fossil fuels. Biomass available as a substitute for fuels includes traditional agricultural crops and residues, animal manure, forests, aquatic plants, and algae and other microorganisms. Biomass contains energy stored from the photosynthetic process: starches, sugars, cellulose, and lignin. Dry biomass contains perhaps 7000 Btu/lb — more than half as much as a pound of coal. Biomass has many competing uses: as food, fiber, soil organic matter, bedding, and structural material; in addition it can be used for fuels.

Dry biomass can be burned to produce heat, steam, and/or electricity; or for use in mobile vehicles, it can be converted to liquid or gaseous form by anaerobic fermentation, alcoholic fermentation, gasification, and other processes.

The potential for biomass production

Biomass from agricultural residues. An estimated 400 million tons of residues is produced each year from ten major crops in the United States. Not all residue is collectible with present machinery, and some must remain on the land to maintain acceptable erosion limits. The above estimate excludes at least 1 ton per acre of corn and soybean residues and ¼ ton per acre of small-grain residues that were likely left in the field.

[12] Adapted from: B. A. Stout and T. L. Loudon, "Energy from Organic Residues" presented at United Nations Environment Program-Food and Agriculture Organization Seminar on Residue Utilization, Rome Italy (1976). B. A. Stout "Agricultural Biomass for Fuels" prepared for the Agricultural Research Institute, Washington, D.C., (December 1, 1979); John Posselius and B. A. Stout, "Crop Residue Availability for a Fuel", *Proceedings*, Bio-Energy '80, Atlanta, Georgia (1980).

Seventy-eight million tons of collectible **surplus** residue (usable) might be considered for fuel (Table 11). Forty-four percent of the usable residue is in four midwestern states, Minnesota, Illinois, Indiana and Iowa and 73% of the total (56 million tons) is in those states plus California, Kansas, Nebraska, Ohio, South Dakota, Texas, Washington and Wisconsin.

Table 11. Collectible surplus residues

Crop	Amount (millions of tons)
Corn	37
Small grains	34
Rice	5
Sorghum	1
Sugar cane	½
Total (approximate)	78

Source: Stanley Barber, "Energy Resource Base for Agricultural Residues and Forage Crops," presented at the Mid-American Biomass Energy Workshop, Purdue University, May 21, 1979.

Growing Crops for Fuel. Agricultural crops grown under modern management methods are effective multipliers of fossil energy, through the capture and conversion of solar radiation. Table 12 shows yields in tons and net energy, as well as the net energy ratio for various crops. Yields averaged over 15 $t/hm^2/yr$ for Napier grass, kenaf, and corn.

Table 12. Energy potential for various crops

Crop	Yield, $t/hm^2/yr$[a]	Net energy produced GJ/hm^2[b]	Net energy ratio[c]
Alfalfa	12.1	202	15.1
Corn, whole	19.3	324	13.0
Corn, kernels	7.7	161	8.6
Kenaf	19.5	309	13.6
Napier grass	50.2	803	13.4
Slash pine	14.5	238	26.8
Wheat, whole	7.4	114	8.0
Wheat, grain	2.9	43	3.4

[a] $t/hm^2/yr$ means metric tons/hectometer²/year; a hectometer is 100 meters.
[b] GJ/hm^2 means gigajoule/hectometer²; a gigajoule is 10^9 joules.
[c] $\frac{\textit{gross energy produced} \times \text{energy input}}{\text{energy input}}$

Source: H. M. Keener and W. L. Roller, "Energy Production by Field Crops," American Society of Agricultual Engineers paper 75-3021 (1975).

Opinions differ on the availability of land for biomass production. An estimated 90% of the 470 million acres of U.S. cropland is of sufficient quality to support biomass production. However, about half of this land needs conservation measures to prevent environmental and soil degradation. An additional 220 million acres of pasture and rangeland have the potential for sustaining biomass crops. Another 160 million acres of forestland might be suitable for growing biomass for energy. Whether or not this land would actually be used for biomass crops depends on price-cost relationships.

Forages. The present production of forages on pasture and haylands in the United States provides feed for the nation's livestock but little surplus. If a new market develops for biomass fuels, millions of tons of additional biomass could be produced from the current pasture and hayland acreages (Tables 13 and 14). The **surplus** in Table 14 is 102 million tons if 1 t/acre is produced above livestock feed requirements and 204 million tons if a surplus of 2 t/acre is produced. Additional fertilizer would be needed, but a favorable ratio of energy output to input of 8:1 for producing biomass on haylands is likely.

The combined output of residues and forages could produce 2-4 quads of energy or 4-8 billion gallons of alcohol per year, enough to substitute for 5-9% of the nation's gasoline supply.

Table 13. Present pasture and hayland in the eastern United States
Values in millions of acres

Region	Hay	Cropland pasture	Non-cropland pasture
Northeast	6	4	3
Northcentral	17	20	21
South	7	23	25
Total	30	47	49

Source: Stanley Barber, "Energy Resource Base for Agricultural Residues and Forage Crops," presented at the Mid-American Biomass Energy Workshop, Purdue University, May 21, 1979.

Table 14. Surplus biomass potential from pasture and hayland in Eastern United States (yield in addition to livestock needs)
Values in millions of tons

Region	1 t/acre	2 t/acre
Northeast	12	24
Northcentral	47	95
South	43	85
Total	102	204

Source: Stanley Barber, "Energy Resource Base for Agricultural Residues and Forage Crops," presented at the Mid-American Biomass Energy Workshop, Purdue University, May 12, 1979.

Livestock and poultry manure. Results of a mathematical model to estimate manure production indicate that over 112 million tons are produced annually within the United States (Table 15). About 47% of the manure is produced by beef cattle on the range, 23% from dairy cattle, 12% from hogs, and the remainder from sheep, layers, broilers, and turkeys. About half the manure voided is estimated to be economically recoverable (Table 15).

Table 16 shows the energy potential of manure as a fuel for direct combustion and for conversion to methane, assuming 6000 Btu/lb for dry manure and 600 Btu/ft^3 for biogas.

Table 15. Manure production and losses
Values in thousands of tons

Type	Initial	After losses	Collectible
Beef cattle	52,000	41,000	1,900
Feeder cattle	10,000	10,000	10,000
Dairy cattle	25,000	24,000	20,000
Swine	13,000	9,000	6,000
Sheep	4,000	3,000	2,000
Layers	3,000	3,000	3,000
Turkeys	1,000	1,000	1,000
Broilers	3,000	4,000	4,000
Total	112,000	95,000	47,000

Source: D. L. Van Dyne and C. B. Gilbertson, *Estimating U.S. Livestock and Poultry Manure and Nutrient Production*, U.S. Department of Agriculture - ESCS bulletin no. 12 (1978).

Table 16. Energy potential of manure as a fuel[a]
Values in (10^6 Btu/animal)/year[a]

Animal	Direct burning	As methane
Beef cattle	15.3	6.3
Feeder cattle	9.4	4.2
Dairy cattle	22.8	9.4
Swine	2.5	1.2
Sheep	2.2	0.95
Layers	0.11	0.06
Broilers	0.08	0.04
Turkeys	0.31	0.16

[a] As voided 6000 Btu/lb dry weight and 600 Btu/ft^3 biogas.

Forest Products. The equivalent of about 4 quads of energy is harvested annually from our forests for lumber and paper products. These products, while more valuable than fuel, could be utilized for energy.

The forest-products industry already produces about 1 quad of energy from its residues. An additional 0.5-0.1 quad could be realized from agricultural and forest residues combined.

Hardwoods growing on southern pine sites are a virtually unused source of biomass. To avoid destroying these trees during site preparation, two utilization schemes have been proposed. The energy-self-sufficient Koch approach could recover 67% of the biomass of all hardwood tree species as solid wood products. Another proposal calls for chipping entire hardwood trees in the woods. Chips can be used for fuel, chemical production, or fiberboard.

DOE estimates of available biomass raw material

Assuming no new or marginal cropland is brought into production, available grain crops are generally those that can be grown on existing cropland in the absence of any U.S. Department of Agriculture policy of production restriction and that are not needed for projected demands of food, feed, or export markets.

The maximum available U.S. biomass resources total 800 million dry tons annually (Table 17). Wood comprises 61% of this total; agricultural residues, 23%; municipal solid waste, 10%; grains, 5%; and food processing wastes, 1%. A more conservative estimate (Table 18), shows that 80.2 million dry tons of biomass are potentially available from wastes supplemented by grains grown on set-aside lands. Available crop residues exclude an average of 35% of all residues estimated as the minimum the farmer must leave on the land.

Table 17. Projected maximum U.S. biomass resources available

Values in millions of dry tons/year

	1980 Quantity	%	1985 Quantity	%	1990 Quantity	%	2000 Quantity	%
Wood[a]	499	61	464	56	429	49	549	48
Agricultural residues	193	23	220	26	240	28	278	24
Grains[b]								
Corn	22		20		8			
Wheat	12		15		17		20	
Grain sorghum	4		3		3		3	
Total, grains	38	5	38	5	28	3	23	2
Sugars[b]								
Cane			3		13		13	
Sweet sorghum			5		56		159	
Total, sugars			8	1	69	8	172	15
Municipal solid wastes	86	10	92	11	99	11	116	10
Food processing wastes								
Citrus	2		2		3		4	
Cheese	1		1		1		2	
All other	3		4		4		4	
Total, processing wastes	6	1	7	1	8	1	10	1
Totals	822	100	829	100	873	100	1 148	100

[a] Assumes wood from silvicultural energy farms starting in 1995.

[b] Estimates for grains and sugars assume an aggressive development program to establish sweet sorghum as a cash crop. This program would divert land from corn in 1990 and 2000, 4.7 and 7 million acres, respectively.

Source: U.S. Department of Energy, *The Report of the Alcohol Fuels Policy Review*, p. 48.

Table 18. Biomass feedstocks potentially available
Costs in constant 1977 dollars

Biomass feedstock	Millions of dry tons	Millions of bushels	Percent of total available (%)	Cost Dollars per dry ton
Cheese whey	0.9		80	21
Citrus waste	1.9		80	86
Other food wastes	1.7		50	45
Corn	16.0	640	80	115
Grain sorghum	2.7	110	80	104
Sugarcane	2.6		100	88
Wheat	11.4	420	80	135
Municipal solid wastes	43.0		50	5
Total	80.2			

Source: U.S. Department of Energy, *The Report of the Alcohol Fuels Policy Review*, p.48.

Significance of biomass fuels

The technical energy potential for direct combustion of biomass (excluding grains) is estimated at 1.6-3.2 quads. The **technical potential** for alcohol production (using residues, forage, and grains) would be 11 to 18 billion gal/year, or 9-15% of the U.S. gasoline consumption.

Biomass Conversion Technologies

Many processes or technologies exist for converting biomass to a more useful form for fuel or industrial feedstocks. They are classified as wet or dry processes (Fig. 19). Dry processes include direct combustion, gasification, methanol production, and oil extraction; wet processes include anaerobic digestion and ethanol fermentation.

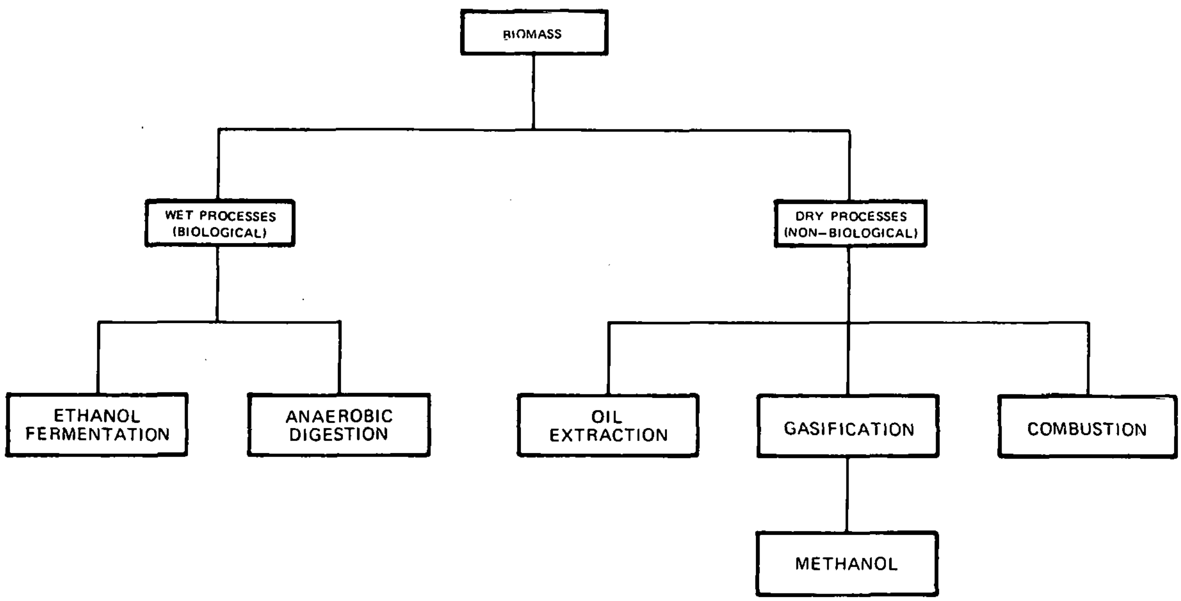

Fig. 19. Some options for converting biomass to heat energy, or liquid or gaseous fuels.

Direct combustion — Burning in an excess of air

There are two types of air-suspended combustion systems: those which suspend the burning fuel in the gas stream in the combustion enclosure and those which suspend the fuel in the gas stream and in another medium, the fluidized bed.

Gasification

Burning in a controlled atmosphere.[13] Gasification is the conversion of a solid or a liquid to a gas. If the oxygen supply is restricted, incomplete combustion occurs, releasing combustible gases such as carbon monoxide, hydrogen, and methane. A solid residue or char remains. Methanol can be produced by further processing of these gases.

Heating in the absence of air. Pyrolysis is the transformation of an organic material into another form by heating in the absence of air. If heat is applied slowly, the initial products are water vapor and volatile organic compounds. Increased heat leads to recombination of the organic materials into complex hydrocarbons and water. The principal products of pyrolysis are gases, oils, and char.

Oil extraction. Seeds from sunflower and soybean crops contain oils that can be used to fuel diesel engines. Extraction is by conventional methods.

Anaerobic digestion[14]

Anaerobic digestion is a conversion process for wet biomass such as animal manure, municipal sewage, and certain industrial wastes. Through this process, complex organics are converted into methane and other gases. The by-product effluent can be used as fertilizer or animal feed.

Anaerobic digestion is a biological process carried out by living microorganisms:

organic matter + bacteria + water + methane + carbon dioxide + hydrogen sulfide + stabilized effluent

this process occurs only in the absence of free oxygen. Methane-forming bacteria are sensitive to environmental conditions such as pH (6.6-7.6 optimum), temperature (95° F and 130° F, two preferred levels), and carbon-nitrogen ratio (30:1 optimum).

Ethanol production[15]

Ethanol is produced by fermentation of sugars and distillation to increase the concentration. If a starchy feedstock is used, the starch is first converted to sugar by enzymes. Research is under way to develop practical processes for conversion of cellulosic feedstocks to sugars by acid to enzyme hydrolysis. The Bureau of Alcohol, Tobacco and Firearms requires that fuel alcohol be denatured (rendered unfit for consumption) before it is sold.

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[13] John Posselius, Claudia Myers, B. A. Stout, and Jun Sakai, *An Updraft Producer Gas Generator*, AEIS, 394, Michigan State University, East Lansing, Michigan, 1979.

[14] W. T. Rose, T. L. Loudon, and B. A. Stout, *Anaerobic Digestion of Livestock Wastes into Methane Gas*, AEIS 403, Michigan State University, East Lansing, Michigan, 1979.

[15] Robert Ofoli, and Bill Stout, *Making Ethanol for Fuel on the Farm*, AEIS 421, Michigan State University, East Lansing, Michigan, 1980.

The Economics of biomass conversion and use

Biomass for fuels is a complex subject involving growth, collection, densification, transport, conversion, and utilization of organic materials. If surpluses exist or if more biomass can be grown than is needed for human and animal diets, the biomass may be considered for fuels. But if it is used for fuel, its impact on food prices and availability must be carefully considered.

Gasifiers

An experimental gasifier has been installed at Diamond/Sunsweet in Stockton, California. Walnut shells are used to produce a low-Btu gas to fire a steam boiler. The fuel loading rate (slightly over 1 t/hr) produced enough low-Btu gas to sustain a steam production rate of about 8500 lb/hr at 15 psi.

In the example that follows, the biomass feedstock (walnut shells) is free and already collected. Usually, the added cost of purchasing the feedstock and transporting it to the gasifier must be included.

Capital costs for the gasifier	$ 85,800
Capital costs for piping, burner, and controls	40,000
Total capital costs	$125,800

Annual cost of gasification equipment (% of new cost):

Interest and depreciation	17%
Repairs and maintenance	3%
Taxes and insurance	2%
	22%

Annual capital cost (125,800 × 22%)	$27,676
Annual labor cost	6,000
Annual cost of disposing of residue	28,571
Total annual cost	$62,247

Heat produced 85,000 million Btu

Cost of heat from gasifier $\dfrac{\$62{,}247}{85{,}000 \text{ million Btu}} = 73¢/\text{million Btu}$

Hodam and Williams estimate the capital cost of a gasifier system at $75,000-150,000 depending on unit size. A 36-in. gasifier consumes about 700 lb/h of biomass fuel producing 4 million Btu of hot gas.

Anaerobic digesters

In biogas-powered stationary engines, waste heat can be recirculated in the digester coil, and gas can be used as it is produced without a compressor storage unit. Full engine power is realized only if carbon dioxide is removed from the biogas mixture to increase the energy content of the gas. Longer engine life is attained if hydrogen sulfide is also eliminated from the gas before use.

Methane-driven stationary engines have a variety of uses, but two likely ones are for pumping irrigation water and generating electricity. A reliable gas supply will be needed when biogas is used for irrigation pumping. Consider the energy required to pump 100 gal/min a distance of 20 ft for a surface irrigation system:

$$P = \frac{Qwh}{33{,}000\ E}$$

where
P = power input to the pump (hp),
Q = stream size, (gal/min)
w = density of water, (8.34 lb/gal),
h = total head (ft),
E = pump efficiency (about 0.7 for well-designed pumps),
1 hp = 33,000 ft-lb/min;

thus,

$$P = \frac{100\ (8.34)\ (20)}{33{,}000\ (0.7)} = 0.72 \text{ hp.}$$

To deliver 0.72 hp to the pump, a biogas engine at only 24% efficiency requires a power input of 3.0 hp. To irrigate for 10 hr, 30 hp-hr of energy are needed.

$$30 \text{ hp-hr x } \frac{2546 \text{ Btu}}{\text{hp-hr}} = 76{,}400 \text{ Btu.}$$

The energy density of biogas is 600 Btu/ft^3; therefore, 127 ft^3 of biogas is required.

$$76{,}400 \text{ Btu}/(600 \text{ Btu/ft}^3) = 127 \text{ ft}^3 \text{ of biogas.}$$

This is equivalent to the manure produced by 21-23 mature (200-lb) pigs being fed a U.S. finishing ration.

When using biogas for electrical generation, an additional 5% loss occurs due to the generator, coupled with other potential inefficiencies at the point of application. Despite these problems, electricity generation seems popular, probably because electrical demand is less **seasonal** than heat demand.

Biogas may also be used to heat livestock buildings by scrubbing H_2S only, but the 30-40% CO_2 will necessitate additional venting and, therefore, more heating energy.

Ethanol and methanol production

The DOE *Alcohol Fuels Policy Review* projects ethanol costs as shown in Table 19. Figures 20 and 21 show how changes in feedstock costs affect the price of ethanol. The same analysis as that used in Table 19 projects methanol selling prices of $0.27 to 0.49/gal from coal, $0.85 to 1.20/gal from municipal solid waste, and $0.65 to 0.81/gal from wood.

The technology and thus the economics of producing alcohol are quite dynamic. There is every reason to expect that with improved technology — heat recycling, improved distillation methods, membrane separation, and integrated systems that permit wet feeding of by-products — the energy balance and economics of alcohol production can be improved.

Table 19. Economics of ethanol production based on commercially available technology, 1978

Assumes 100% company equity, 20-year plant life, and a 7% inflation rate

Feedstock for ethanol production	Feedstock price ($)	Production rate (gal/yr)	Plant capital (thousands $)		Components of selling price $/gal				Estimated alcohol selling price ($/gal)	
			Fixed investment	Working capital	Feedstock costs	Direct operating costs	Fixed costs	By-product credits	15% DCF[a]	20% DCF
Milo	2.20/bu	50,000	58.0	5.5	0.88	0.28	0.11	0.42	1.02	1.13
Wheat	3.15/bu	50,000	58.0	7.9	1.26	0.30	0.11	0.53	1.31	1.44
Corn with corn stover as fuel	2.30/bu - 25.00/t	50,000	57.0	5.8	0.89	0.30	0.11	0.38	1.09	1.21
Sugar cane	65.00/t	25,000	58.4	4.12	1.20	0.34	0.18		2.07	2.30
Cheese whey	3.00/t	2,800	10.2	0.41	0.42	0.89	0.31	0.83	1.25	1.63
Corn (base case)	2.30/bu	50,000	58.0	5.7	0.89	0.27	0.11	0.39	1.05	1.16

[a] Discounted cash flow (DCF) takes into account the time value of money and is based on the amount of unreturned money after taxes at the end of each year.

Source: U.S. Department of Energy, *The Report of the Alcohol Fuels Policy Review*, pp. 74-75.

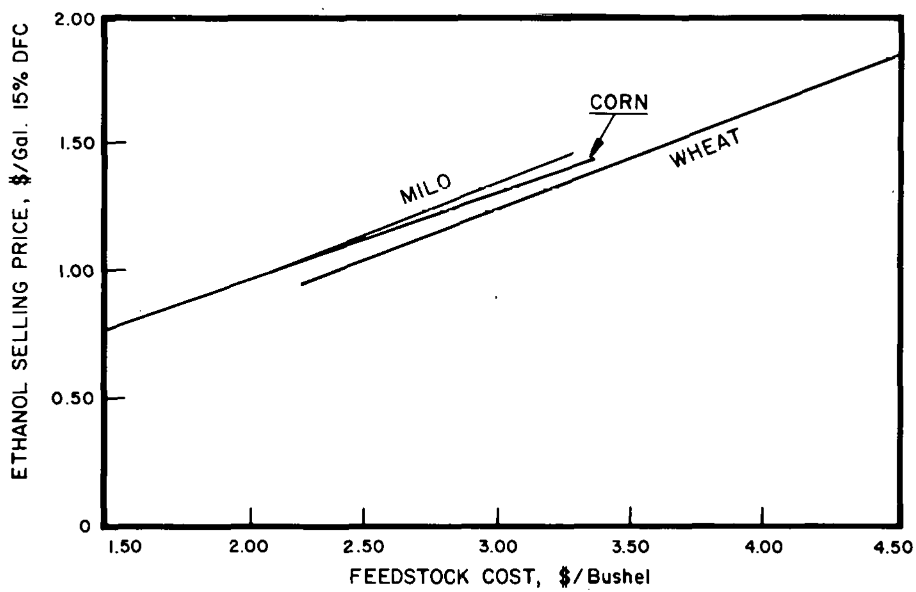

Fig. 20. Sensitivity of ethanol selling price to feedstock costs. Source: Department of Energy, *The Report of the Alcohol Fuels Policy Review*, p. 93.

Utilization of ethanol as a fuel[16]

Ethanol is a satisfactory fuel for spark-ignition engines. It is clean burning, has a high octane number, and blends easily with gasoline if little or no water is present. The heat content of ethanol is about two-thirds that of gasoline. Ethanol's excellent combustion characteristics result in somewhat better performance (mpg) than its heat content alone would indicate.

Gasohol, a mixture of 10% ethanol and 90% unleaded gasoline, is available in hundreds of stations in many parts of the country and can be burned in spark-ignition engines without modification.

As a fuel for diesel engines, ethanol is less attractive. Ethanol has a low octane number. It can be used in diesel engines by aspirating droplets into the intake manifold or by combustion to a dual-fuel engine, but widespread commercial use remains uncertain.

[16] Alan Rotz, Marcio Cruz, Robert Wilkinson, and Bill Stout, *Utilization of Alcohol in Spark-ignition and Diesel Engines*, AEIS 423, Michigan State University, East Lansing, Michigan, 1980.

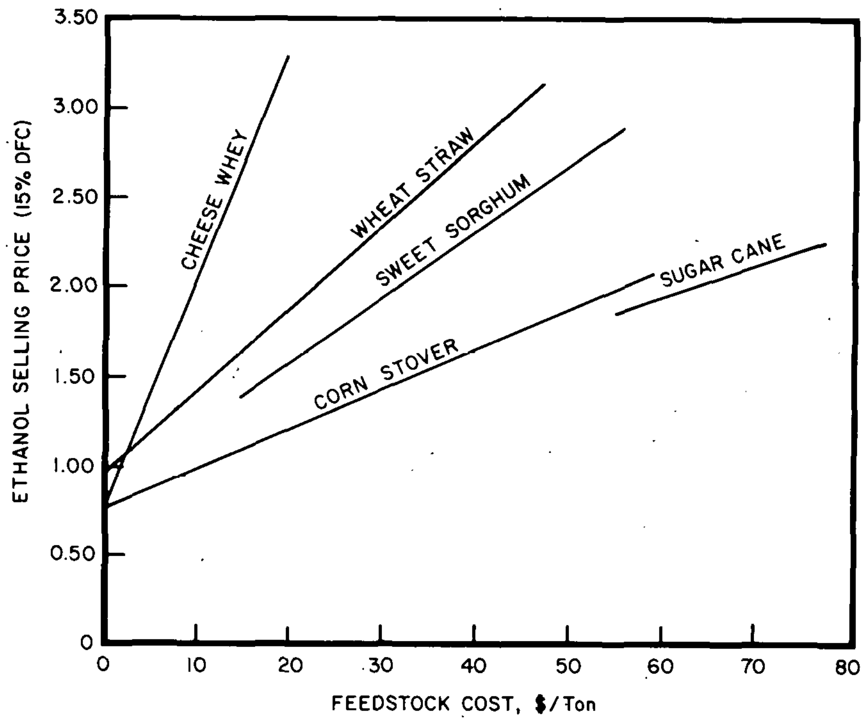

Fig. 21. Sensitivity of ethanol selling price to feedstock costs. Source: Department of Energy, *The Report of the Alcohol Fuels Policy Review*, p. 94.

Discussion

Millions of tons of biomass could be available for fuel. Where biomass is available and the technology for using it as a fuel in a cost-effective manner exists or can be developed, it seems prudent to do so.

Biomass fuels can provide only a small percentage of our nation's energy needs — but even a 1% reduction in our usage of non-renewable resources is significant.

Biomass technology

The technology for using biomass fuels exists or is being developed. In the past, biomass fuels were unable to compete with inexpensive oil and gas, but drastically higher petroleum prices and uncertain supplies are changing the picture. Further research is needed on the technical aspects of biomass for fuels along with a commercialization program where the economics make sense. Several research priorities have already been established.

- grain production improvement to increase starch production per acre (increased cellulose yields will provide feedstock and fuel for distilling if cellulosic conversion to alcohol is commercialized; new varieties and species should be screened)
- grain residue collection to reduce costs
- grain processing including the **whole-crop** concept
- fermentation, including continuous process
- distillation, to reduce energy requirements

- by-product utilization, including feeding of distillers' grains; impact on other feed grains
- residue utilization in both agriculture and forestry

An alternative farm program

Crops may be grown specifically for fuel with net energy returns ranging from 3.4 for wheat grain to 8.6 for corn kernels and 15.1 for alfalfa. Unconventional crops that produce oils or hydrocarbons may be introduced. Acres that have been set aside or marginal may be brought into production for growing energy crops.

From 1961 to 1977 the U.S. government paid farmers an average of $1.6 billion each year for land retirement, land adjustments, and deficiency payments, exclusive of cotton, tobacco, wool, milk, and commodity programs. An alternative farm program designed to encourage biomass production could produce about 2.5 billion gal/year of alcohol or about 2% of our current gasoline consumption at essentially the same cost, $1.6 billion. The annual savings in foreign exchange from reduced oil imports would amount to $1 billion at early 1979 oil prices.

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Questions and Answers

John D. Selby, P.E. (Consumers Power Company): One of the things that concerns me when I hear talk of using the residue from grain crops, to generate electricity and so forth, is how the soil is affected. Has agriculture changed to the extent that this is no longer a necessary concern?

Dr. Stout: That's something that we also worry about. No one advocates indiscriminate removal of residues from the soils. Any of you who are farmers or even gardeners know that organic matter is necessary to produce good crops and to protect the soil from excessive erosion. We have given careful attention to this issue and have a computer program that considers the characteristics of individual fields (e.g., the topography, the climate, and the type of crop) and determines the tolerable soil loss and the percentage of residue that could be used for fuel. We have learned that with today's high-yielding crops, there is a surplus in many cases. Determining whether this surplus can be collected and converted to liquid or gaseous fuels economically will require more attention.

Neil Norman, P.E. (President, California Society of Professional Engineers): I'm concerned about the cost effectiveness of the solar option when it is augmented with tax credits. If we're really going to look at the cost effectiveness on a massive scale (and in California attempts are being made to implement solar heating on a massive scale), we have to look at the actual cost because the money used for the solar option is being diverted from other potential energy forms. The cost estimates that you presented appeared to be at least twice as high for solar energy as for alternative sources. Would you address that?

Dr. Clark: Whether we should include the amount of a subsidy — namely, the costs to the taxpayers in the total cost of a given solar system is a good question. Our figures do not include that cost, which is rather difficult to predict, but I'll answer the question thusly. When a person determines whether to install a system on his structure, he looks at the costs to himself, either as an individual or as an industry. If, under our present tax credits, those costs reflect basic subsidies, the actual cost probably would be larger, but that is not what an individual would base his decisions on. We could extend this discussion to all kinds of federal and state credit (for example food subsidies, subsidies in the nuclear system, and subsidies in the coal mines), so if we ask the question for solar, we have to ask it for everything. What we have given you here is the costs to you — even though some of those costs entail subsidies that are paid by your neighbors in other states and in your own community.

Now, maybe we should debate the question of subsidies. Given the pure, unfettered free market, these subsidies are not needed or desired. The free market could, in fact, bring solar on board at the appropriate time in the most innovative, effective way that American technology and industry has demonstrated it can do. Do we have time for the free market to act? I'm not sure the answer to that question is yes. If you integrate the thoughts of the previous speakers, maybe we don't have any more than 5 or 10 years to bring on alternate forms. Therefore, some high risk element ought to be introduced, and the best that the federal government and states have proposed so far are the tax credits and the solar banks.

The figures we have given, then, are the cost to you — even though you are asking your neighbors to help pay for it. But you are asking your neighbors to help pay for your food, your electricity, and all the other subsidized items, and you have to decide philosophically whether you're willing to accept that.

Carl Roman, P.E. (Allentown, Pennsylvania): You presented a very optimistic viewpoint on this type of energy, almost to the point of making me question your credibility. Would you address solar energy from a pragmatic viewpoint in order to present a perspective that is between yours and that of some of the other speakers and to try to be frank about this matter?

Dr. Stout: My presentation used figures from the president's *Domestic Policy Review of Solar Energy.* Those figures were the optimistic ones, that assume tax credits and various incentives to bring acceptance of Solar energy more quickly than the free market would. As for my credibility, you must answer that question for yourself. I'm simply passing on information from the *Domestic Policy Review.* I'll also say that I just produced, with Mr. Patton's help, the slide tape on nuclear energy that was referred to earlier and that my position is exactly that of NSPE — that all feasible domestic energy sources should be developed, including solar energy.

Dr. Robert L. Hershey, P.E. (Science Management Corporation, Washington, D.C.): Could you comment on methanol from biomass versus methanol from coal?

Dr. Stout: Today we hear so much clamor about ethanol as a fuel. It's my prediction that the interest in ethanol will fall to a more realistic level. Ethanol will make a small but significant contribution to the nation's liquid fuel needs, and methanol probably has the potential to play a much larger role in the future.

Marvin Specter, P.E. (Chairman, Constitution and Bylaws Committee, NSPE, White Plaines, New York): I live and work in Weschester County in New York and am just about 8 or 10 miles downwind of the Buchanan Nuclear Reactors, which some people consider the most critical in the nation in terms of their proximity to population centers. We benefit, however, from having some of the most effective environmental obstructionists in the country, and they've been making a concerted effort to handle our situation for quite a few years. Last year, when I happened to be flying over the Hudson River, I noticed an incredible mass of humanity on the site of a land development project near the tip of Manhattan. The crowd turned out to be the Jane Fonda and friends antinuclear rally. Now I see on TV that the records and tapes from this rally are being marketed with a tremendous advertising promotion and are going to bring a lot of revenue, and the end result is more money and more antinuclear publicity.

Now I want to tie this example to Dr. Clark's earlier statements about spending money and subsidizing things. We're facing in this country the question of survival, and the price not the question. We've got to pay the price for energy independence. Just this past spring I wrote my local congressman to object to a position he had taken on a key national issue. I guess a lot of other people also wrote him because within less than a month he replied that he had given careful thought to the matter and had decided to change his position. The voice of the people was heard on that issue, and I am confident that the voice of the people as spoken by **NSPE**, engineers and friends will be heard on these **National energy issues.**

Dr. Lynn A. Weaver, P.E. (Director, School of Engineering, Georgia Institute of Technology): Do the cost goals for photovoltaic systems include storage?

Dr. Stout: I was quoting DOE figures and gave you different ones for the cells themselves and some for the system. I believe the figure for the system includes storage.

Marty Rowland (Michigan Pro-Energy Coalition, Ferndale, Michigan): Mr. Norman seemed to be suggesting that the money spent for the subsidies towards solar energy could have been better spent on energy technologies with quicker paybacks. Could you discuss the time required for the payback in energy produced from the energy invested in a solar energy facility, capable of generating power for a large city?

Dr. Clark: The matter of energy payback on solar collectors is rather uncertain. Stanford Research Institute predicts less than a year if the solar-collector is copper, aluminum, or steel. I've seen energy payback or energy efficacy figures as high as 5 to 10 years for the same systems, so the actual figure probably lies somewhere between the two estimates. The truth is that we probably don't know the payback time. We can be sure, however, that the energy payback will be about four or five times the energy required to build these systems. The systems I'm speaking of, flat-plate collectors and light concentrators, are not complex and procedures for manufacturing them are known. The energy required to build them will approximately equal that for domestic furnaces and plumbing systems. The energy payback, then, will be positive by a factor of 5 to 10 because the life of these systems will be 20, maybe 40 years, when the designs are complete.

Question from the audience: How does the payback period for nuclear energy compare with that for solar energy?

Dr. Clark: I've seen an array of figures and thought at the time that solar was a bit more competitive, but I wouldn't want to make that statement here. There are others here more qualified to address that topic.

I would like to say something about the earlier question of Dr. Stout's credibility. I think the questioner may have been wondering about the reality of the figures provided by the *Domestic Policy Review of Solar Energy,* and I'm inclined to agree with him on that issue. The *Domestic Policy Review* identified only goals, and those at the upper and middle scenarios probably are not achievable by the target dates. If you analyze what is required to achieve those goals, and by focusing on achieving them rather than measuring your rate of progress, the goals can grow and have that purpose. Take the photovoltaic goals, for instance. Although we may not make the 1986 costs in 1986, we may make them in 1996, but the goals are the guide to tell us how we're doing. If, however, the goals are viewed as something to be accomplished by the year stated, the United States would have to have increased the production level of solar collection systems by a factor of 25 starting 8 months ago and would have to maintain that level for 20 years to make even the modest goal.

Now, during the two years, that I was president of the Central Solar Energy Research Corporation here in Detroit, we examined the production and design problems of these systems. Furthermore, we examined the *Domestic Policy Review* goals from the standpoint of what was necessary to accomplish them, and these are the figures we came up with. If we look at wind machines, we have one big one, but we would need to produce about 1700 per year for the next 20 years to make the wind goals. The goals are thus going to be massive challenges for the country, but I believe the questioner called them incredible. They are incredible only if you say the goals are there to be met without question rather than to enable measurement of our progress. So far our progress doesn't look very good, but maybe we, as a group of technologists and engineers, can improve that progress.

Percy Brewington, Jr., P.E. (Deputy Manager, Enrichment Expansion Projects, DOE — Oak Ridge Operations Office, Oak Ridge, Tennessee): Hydro power is sometimes included in solar power totals. Did the *Domestic Policy Review of Solar Energy* projection of 16% of the nation's fuel displaced by solar by the year 2000 include hydro?

Dr. Stout: Yes. The following table gives the complete *Domestic Policy Review* projections for the maximum practical use of solar technologies.

Category	Potential for energy generation (quads)	Percentage of national energy use
Heating of space and water	5.6	4.9
Photovoltaics	1.0	.9
Wind	1.7	1.5
Biomass	5.5	4.8
Hydro	3.8	3.3
Other	0.5	0.4
Total	18.1	15.8

Source: Department of Energy, *Domestic Policy Review of Solar Energy*, TID - 28834 (1979).

Phil Owens, P.E. (Sandia Labs, Albuquerque, New Mexico): Solar use in power plants, through steam generation, was not mentioned. Is this not at all feasible?

Dr. Stout: Many aspects of solar energy were not mentioned because of time and space limitations. Solar energy involves a vast collection of nearly unrelated technologies; the only thing they all have in common is the sun. Considerable R&D related to solar steam generation is under way, and the practical feasibility of this solar use is still being determined.

Norman G. Schaffer, P.E. (N. G. Schaffer Engineering, Emmaus, Pennsylvania): What about high-altitude satellite photovoltaics with transmission to earth as high-frequency power?

Dr. Stout: Some people who have studied this in detail feel there is great potential for solar power satellites. A leading advocate is Peter E. Glaser of Arthur D. Little, Inc. Critics, however, are worried about the possible radiation hazards and the tremendous costs.

Les Opachak, P.E. (Detroit, Michigan): What is the highest percentage of efficiency that can currently be expected in the conversion of grain to ethanol?

Dr. Stout: This is a complex question that is hard to answer concisely without a great many qualifications, but the following table gives one answer.

	Total energy analysis (Btu/gal)	
	Irrigated corn	Dry land corn
	Inputs	
Farm sector	37,600	29,700
Off-farm transportation	4,100	4,100
Alcohol plant	68,300	68,300
Total A	110,000	102,000
	Outputs	
Ethanol	84,600	84,600
Distillers dried grains (10% moisture)	34,100	34,100
Carbon dioxide		
Total B	118,700	118,700
Energy Balance (B - A)	8,700	16,600

Source: Robert Y. Ofoli, *Energy Balance Analysis for Fuel Ethanol Production*, M.S. thesis, Michigan State University, 1980.

A positive energy balance of 1.08 is achieved from irrigated corn and of 1.16 from dry land corn. If coal or biomass fuels are used in the alcohol plant, premium fuel gains of about 2.0 or 2.5 are possible.

Closing Comments

Pat Patton: Before we leave, I'd like to recognize Dr. Paul Robbins. Paul is our retired executive director. He put in 3 decades of work in our behalf. One of the unique things about him is that he has met with every president from Harry Truman on discussing engineering problems with them. I think every engineer in this room has a tremendous debt of gratitude to Dr. Robbins. I would like to have a word from him before we close.

Paul Robbins: You're very kind, Pat, and I appreciate the opportunity, although I don't know what I can add. There has been such a tremendous array of talent here, and the questions have been so incisive, that I feel very humble. My one comment is that perhaps an overriding objective of NSPE and the Energy Awareness Fund is to make possible this kind of thing at the grass roots level. All of us attending here are knowledgeable and concerned about energy. The real solution to our energy problem has to be a massive understanding on the part of the public. We, as engineers, have a credibility coming from a quasi-unbiased position, at any rate. We have studied the problem more than many others have; and we do know the implications and, as has been brought out here so often, the limitations. I think that, if we can possibly get to the public through the literature and the chapters of NSPE (and we are ideally suited to do that), we can provide a tremendous service in making the public aware of the problem, the possible solutions, the limitations, and the much more sane approach to energy than the hysteria and the Jane Fonda approaches. I would hope that, as we go back to our local chapters, we endeavor to establish some sort of a focal point for this kind of study. There's plenty of written and visual material. Let's try to get this information out so that the people understand it and make rational decisions, so that their thoughts are made known to those policymakers who have to make the ultimate decisions.

Pat Patton: As part of its energy awareness efforts, NSPE and its Energy Committee are producing a series of 35-mm slide presentations accompanied by cassette tapes that will fit an ordinary player. We have one on nuclear power which will be shown on Friday morning at this conference. We have one on coal close to completion, and we plan others on oil and gas, energy conservation, and all forms of energy. As an individual, you can buy this one on nuclear power for $50.00. I think it's the intention of the Energy Committee to see that every chapter of NSPE gets one, probably free. We are asking the chapters all to raise $1000, and they'll get something in return. Our thought is that every engineer can take these presentations and the accompanying fact sheets and show this information to schools and church groups. Professional engineers have credibility; the requirements to become one are rigorous, you have to practice for five years, you have to pass an examination. We need to get all engineers and scientists in the country involved in efforts like that, in holding luncheons and seminars like this one we have today. We need to repeat these on a massive scale all across the country in the next couple of years. We're preparing a booklet to be available shortly on how to hold a meeting like this, down to how to do the name tags. In this country, the politicians don't lead; they follow the will of the people. We must start a grass roots effort; that is the commitment that this organization has taken, and we expect to get a lot of company from engineers who don't belong to this society and from scientists in all walks of life. It is our responsibility; the time has come to render a public service, and how well we do it is going to make a difference in whether this country will be a democracy in the decades ahead.

For a list of the items available, see the inside of the back cover.

I want to quote Winston Churchill in the years before World War II, when he said to the British Parliament, "If you will not fight when you can easily win, the day will come when you must fight with all odds against you and your chances of survival are small". This is a fight we can win, but the time to step forward is now so that we won't have all the odds against us and so that our chances of survival won't be small.

This concludes our program. I hope you engineers will leave here with a determination to go out and meet the public and get the facts across.

Thank you very much.

Speaking of Energy . . .

William A. Cox, Jr., P.E.

President and Chairman
Cox-Powell Corporation

NSPE President

One of our biggest challenges is to gain broad public support for the initiatives needed to resolve the energy crisis. Such support requires public understanding of the issues, and the engineering profession has a major responsibility to foster that understanding.

Dr. Paul H. Robbins, P.E.

Retired Executive Director, NSPE
(1946-1978)

NSPE Energy Committee

Periodic gasoline lines, occasional 'brown-outs,' and increasing fuel prices make everyone aware of our dependence on an adequate energy supply and need for conservation of available supplies.

Engineers can provide a needed public service by serving as an unbiased source of information on alternate energy sources, their limitations, availability, use and costs, as well as conservation techniques we all can use. This has the corollary that engineers need to be well informed on these subjects so that information they may be called upon to provide is factual, up to date, and authoritative.

Dr. Lawrence W. Von Tersch, P.E.

Dean, College of Engineering,
Michigan State University

MSPE President

The days of abundant and inexpensive energy are gone and are gone forever. This situation has created a world-wide political and economic crisis which has the potential of catastrophe for the great industrial democracies. The National Society of Professional Engineers must take every possible step to provide the expertise and information which can help our industrial and governmental leaders to create the necessary short-run and long-range energy programs. The Energy Seminar at the 1980 Annual Meeting of NSPE will contribute significantly to this effort.

Speaking of Energy . . .

Edgar K. Riddick, Jr., P.E.

President, Riddick Engineering Corporation
Chairman, NSPE Professional Engineers in Private Practice
Chairman, NSPE Energy Conservation and Management Subcommittee

NSPE Energy Committee

Our Paramount Problem is clear. We are today seriously short of domestic energy supply. The syndrome pervading government and its over-sophisticated efforts at controlling and planning the nation's future energy supply mix will continue to lead to debate, procrastination, an inevitable growing domestic energy supply shortage, and consequently increasing dependence on foreign oil supply.

Our government must, however, play an important role in the development of much needed alternate sources of energy through: Enlightened regulation; Balanced environmental goals; Constructive and productive research, development, and demonstration of new technology; and Encouragement of private-sector investment through tax incentives.

K. C. Yost, P.E.

Vice-President for Planning and Administration
Consolidated Gas Supply Corporation

NSPE Energy Committee

The worldwide energy shortage and the resulting U.S. energy supply crisis pose a major challenge for our country to develop a soundly based peacetime economy. America's technical and engineering talents coupled with its industrial might working together within our free enterprise system can and will assure increasing economic opportunity, allow protection of our environmental heritage, and continue our position as leader of nations.

Speaking of Energy . . .

Donald G. Weinert, P.E.

Executive Director, NSPE

Our profession will have the principal responsibility for designing and constructing the facilities needed if any energy initiatives are to succeed. Input from the engineering profession will be vital to ensure that implementation of plans and policies are economically and technically feasible.

Richard D. Grundy, P.E.

Senior Professional Staff Committee on Energy and Natural Resources United States Senate

NSPE Energy Committee

Our national security is dependent on finding solutions to our energy problems. The United States' historical reliance on petroleum as its principal energy source led to our current excessive dependence on Middle East oil. Short-term solutions therefore must emphasize diplomatic channels coupled with energy conservation in order to buy time for the commercial development of economically feasible longer-term alternatives, particularly for use in transportation. However, any economic comparisons must include the societal costs of our continued dependence on oil imports with their associated balance of payment deficits.

E. E. (Buddy) Moncla, P.E.

Vice-President, Ford, Bacon and Davis Construction Corporation
Chairman, NSPE Professional Engineers in Construction

NSPE Energy Committee

Energy development, use and conservation are areas where the Engineer must play a role. Integrity in engineering design, research and management are most necessary to protect this nation's vital energy needs.

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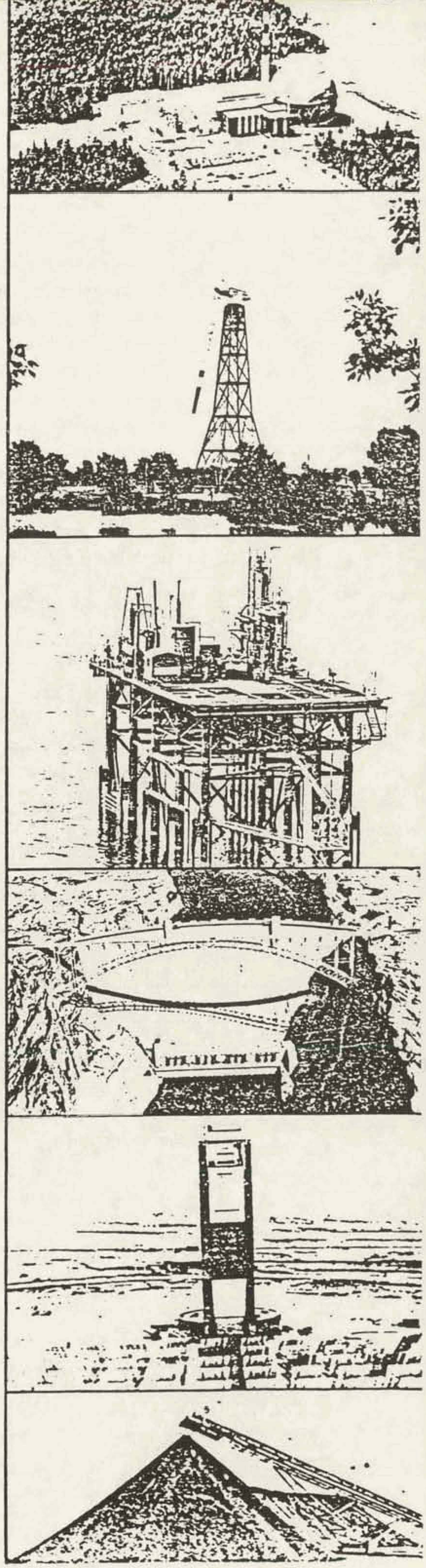
This position paper was prepared under the supervision of Pierce G. Ellis, P.E., 1978–1979 Chairman of the NSPE Energy Committee, NSPE Past President, and retired Senior Vice-President of Wisconsin Public Service Corporation.

"It is the position of the National Society of Professional Engineers that all economically feasible domestic energy options must be developed . . ."*



*From the National Society of Professional Engineers Energy Policy.

The world is now in an era when energy is progressively more expensive. Since the early seventies in the United States an increasing portion of the national income is consumed by energy costs. The nations of the world are interdependent for energy, food, mineral resources, and high technology.

Energy consumption is interrelated with employment, inflation, currency values, and international trade in its impact on national well-being. The U.S. long enjoyed the world's largest domestic market coupled with cheap energy and ample raw materials. As a result, our national income was dependent in only a small way on foreign trade. Growth and prosperity have led to demands beyond domestic energy production, and thus a growing dependence on foreign oil, the price of which is controlled by the OPEC cartel. Payment today for these oil imports requires increased sales of quality American goods, essential technologies, and efficient designs, and all of these must be competitively priced to yield the necessary balance of trade.

Over 40 percent of the world's primary energy demand is met by naturally occurring liquid petroleum. Its seaborne commerce is the largest single element of international trade. Coal, because of its lesser energy content per unit of weight, and natural gas, because of its cost of liquefaction, are small in international energy trade. As long as naturally occurring liquid petroleum is readily available, market forces hold in check the growth of more costly forms of energy such as oil from abundant domestic shale. In like manner, the production of domestic coal is restrained.

However, the earth's reserves of petroleum are uncertain and largely outside the territory, control, and even influence of the U.S. These circumstances, which promise to be of long duration, comprise an economic and security threat to the U.S. To maintain the strong industrial base and defense posture essential to continued independence and prosperity for all our citizens, the U.S. must have reliable energy supplies at predictable and affordable costs.

It is the position of the National Society of Professional Engineers that all economically feasible domestic energy options must be developed, coupled with a vigorous long-term national effort on energy conservation.

Oil imports must be reduced. High demand for foreign oil reinforces high prices for energy; high energy costs aggravate inflation and increase the prices of American products, thereby rendering less competitive the items which must be sold abroad to pay for the imported oil.

Professional engineers are well positioned to contribute to national energy objectives through guidance, evaluation, implementation, and public education.

POLICIES AND ENDORSEMENTS OF NSPE ARE AS FOLLOWS

1. *Regional Energy Characteristics*—While it is unlikely that a widespread absolute shortage of energy will emerge in the next decade, the assurance of appropriate energy supplies *throughout* the United States is fraught with uncertainty. Policies and programs which recognize markedly different regional energy characteristics are essential.

   For example, the energy realities of the Northeast where there are few indigenous fossil fuel resources and expensive seaborne oil is the major source of supply are different from the oil and gas producing Southwest and from the Pacific Northwest where much of the nation's large waterpower resources are located.

   All states and metropolitan areas should be encouraged to draw up long-term energy supply and conservation plans specific to their needs.

2. *Oil*—Oil supplies nearly half the nation's total energy consumption, with a growing proportion from imports. The U.S. should encourage oil exploration and well development in promising areas outside the OPEC cartel. The prospects for uninterrupted supply and reasonable oil prices would be enhanced by more suppliers with diverse political and national objectives.

   Production of domestic oil resources should be encouraged.

   The national petroleum reserve designed to serve the country for 90 days should be expeditiously completed to diminish the impact of any future oil embargo.

   Deep-water ports and offshore unloading facilities for oil should be encouraged.

   Under appropriate arrangements the newly identified oil reserves in Mexico offer benefits to both the U.S. and Mexico, and these mutual benefits should be pursued.

3. *Natural Gas*—Natural gas fills about one-fourth of the nation's total energy consumption, supplying over half the energy users in the residential-commercial sector. American industry has existing heavy capital investments in equipment designed for natural gas.

   Alaska has significant unexploited reserves of natural gas; the U.S. is fortunate in lying between Canada and Mexico, both of which have excesses of natural gas for sale. These resources should be developed and utilized to minimize dependence on imported oil from the OPEC cartel.

   Research and development on U.S. potential sources of gas supply, such as geopressurized zones and various tight rock formations, should be pursued.

4. *Coal*—Coal supplies about one-fifth of the nation's total energy consumption; nearly one-half of the country's electricity is produced from coal. It is our most abundant fuel resource. A prominent feature of the National Energy Act is a prohibition against the use of oil and gas in favor of coal in new utility plants and industrial boiler facilities. Environmental concerns on coal utilization include particulates, sulfur emissions, and a long-term buildup of carbon dioxide in the atmosphere with possible unfavorable climate changes. Environmental concerns also exist with respect to shaft and strip mining of coal.

   A new balance must be reached between concerns for pollution and increased coal production and utilization if a national energy program is to succeed.

   The government owns one-third of all U.S. land. Publicly owned lands contain one-half of all U.S. energy resources including 40 percent of all coal. Laws governing mineral leasing of federal lands must be modified to allow access to these essential resources while reasonably protecting the environment and yielding a fair return to the government. The modernization of coal transportation systems must be facilitated by all segments of industry and government to broaden the areas where coal can be economically competitive.

5. *Nuclear Power*—The prospects for widespread installation of nuclear electric generating plants are diminished from expectations of the early 1970's in spite of high performance, attractive operating costs, and an excellent safety record. Nuclear power plant operation is less vulnerable to interruptions because of strikes, weather, and transportation delays. Capital construction costs have doubled; plants now require over ten years for completion, and the price of uranium has increased over fourfold. Coupled with these factors is a continuing public concern over nuclear proliferation and an increased concern over safety of operation. However, waste disposal remains the most sensitive and crucial of the problems challenging nuclear power growth. Nuclear wastes from military production have been accumulating for three decades and for over 20 years from nuclear electric generating stations, yet no firm date has been fixed for startup of a permanent waste depository.

   Nuclear power is a regional energy resource concentrated in areas of high population density and high electrical power demand, which are poor in fossil fuel resources.

   The time available for transition from an oil-based economy to one based on other energy resources is at most one or two generations. A strong nuclear industry is vital to the country's future.

   Sites and firm construction schedules for nuclear waste depositories must be established.

   Regulatory approval procedures for nuclear electric generating stations must be streamlined.

   Economic deposits of uranium are finite as are oil and coal reserves. Development of the breeder reactor must be continued for nuclear power to help supply the energy requirements of future generations.

6. *Alternate Energy Resources*—All potential energy options, such as nuclear fusion, solar energy, electricity from low-head dams, geothermal, wind power, "gasohol," and municipal waste, must be pursued.

   The engineering community throughout the nation must play a key role in recognizing applications economically appropriate to the locale.

7. *Energy Conservation*—The successful exploitation of present and new abundant energy sources takes time. The best short-term solution is energy management not energy deprivation.

   The energy conservation provisions of federal legislation are far-reaching. Achievement of the aims of this measure poses a major challenge and responsibility to the engineering profession and, more significantly, to the individual citizens of the United States.

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The National Society of Professional Engineers

What it is...

The National Society of Professional Engineers is dedicated to the protection and promotion of the profession of engineering as a social and economic influence vital to the affairs of man and the United States. It is organized on a three-level basis—local, state and national. At each level the organization functions as an autonomous unit dealing with problems affecting engineering practice and the public welfare in its area.

The Society is thoroughly democratic in structure, with all officers at all levels elected annually by direct membership vote.

Who its members are...

The National Society is made up of more than 70,000 professional engineers in all technical branches who practice engineering in accordance with the laws of their states and territories. They are engineers in private consulting practice, industry, education, government service and construction.

When it was founded—and why...

NSPE was founded in 1934 on the premise that every engineer has two distinct professional needs: First, the need for technical branch organizations sponsored and supported by the engineers of that specialized branch; second, the need for an organization devoted exclusively to the professional interests of all engineers, and its activities should be supported by all engineers. Since its founding, the National Society has grown steadily and now has more than 500 local chapters in the 50 states, Puerto Rico, the District of Columbia, the Canal Zone, and Guam.

What it does...

The National Society, at each of its three levels of operation, serves the profession and the public. It has actively promoted effective state registration laws for professional engineers to safeguard the public. It maintains continuing liaison with legislators and government agencies to represent the interests of the engineering profession, and to protect the public safety by setting rigid standards for professional competence and ethical practices.

Activities...

NSPE representatives regularly testify before Congressional committees on legislation of interest to engineers and their profession. A few of the current issues of concern to NSPE are: civil service reform, consumer safety and product standards, development and conservation of national energy resources, air and water pollution control, overhaul of the federal regulatory process, patent reform and labor-management relations. NSPE was instrumental in developing legislation which ultimately resulted in reestablishment of the White House Office of Science and Technology Policy, and has called for a comprehensive Technology Summit Conference bringing together leaders of the engineering and scientific community and top decision makers in government and industry to provide intelligent direction to the nation's technology policy.

NSPE publishes the monthly *PROFESSIONAL ENGINEER* magazine which carries timely feature articles, news briefs, editorials and commentary, and regular sections on such topics as legislation, ethics, Washington developments and new products, to more than 80,000 members of the engineering profession.

The National Society continually promotes the challenges of the engineering profession to junior and senior high school students through extensive career guidance activities and an evergrowing program of grants and scholarships for deserving high school seniors. The Society also carries on a national public relations program calling attention to the role of the professional engineer as a leader in America today, constantly striving to improve our standard of living and create a better environment for all mankind. A national public affairs Community Action Program helps put engineers in the civic spotlight as interested, concerned citizens working to solve local problems. And, the annual observance of National Engineers Week in February, sponsored across the country by NSPE, promotes engineering as a profession and involves industry, government, high schools and colleges, consulting firms and many other engineering organizations.

NSPE's Professional Engineers Employment Referral Service provides placement opportunities for unemployed and underemployed engineers. An NSPE-sponsored home study program helps not-yet-registered engineers prepare for their state P.E. licensing examination; a wide variety of conferences, seminars and publications permits members to stay abreast of trends affecting their practice in engineering. And, the Society has begun a nationwide effort to restructure the engineering educational process to help those entering the profession to be better equipped to deal with the problems of today.

☆U.S. GOVERNMENT PRINTING OFFICE: 1980-640-351/023

Information Available from NSPE Headquarters Concerning Energy

Interested parties may obtain additional information on energy-related matters as listed below through the NSPE Information Center, 2029 K Street N. W., Washington, D. C., 20006. Telephone (202) 463-2310

Title	Description	Prepared By	Cost
Nuclear Energy Issues and Information	35 mm slide presentation of about 23 minutes duration. 78 color slides with written script or, as an option, a tape cassette.	NSPE Energy Committee	NSPE State Societies, NSPE Chapters, Universities, Colleges; $5.00 for postage and handling. Individual NSPE members; $40.00 Non-members; $50.00
Low Level Radiation	35 mm slide presentation of 12-18 minutes duration.	NSPE Legislative Affairs Department	$50.00
NSPE Energy Policy	Brochure which contains the NSPE Energy Policy approved by the Board of Directors at the NSPE Annual Meeting, July, 1979.	NSPE Energy Committee	None
NSPE Energy Awareness Fund	Brochure which describes the goals of the NSPE Energy Awareness Fund.	NSPE Energy Committee	None
An Executive Summary of National Energy Legislation. NSPE Publication No. 1711	Summary of eight pieces of Federal energy legislation passed by Congress from August, 1975, to February, 1979. Includes the five-part National Energy Act of 1978.	Funded by the Riddick Engineering Corporation, Little Rock, Arkansas. Prepared by T. P. Bruderle, Staff Coordinator to the NSPE Energy Committee.	$13.50
NSPE Energy Seminar	Proceedings from the NSPE Energy Seminar, NSPE Annual Meeting, July, 1979.	NSPE Energy Committee	Contact NSPE Information Center
ENERGY in the '80s, Decade of Decision	Proceedings from the Public Awareness Symposium, WATTec Seventh Annual Energy Conference and Exhibition February, 1980, Knoxville, Tennessee	United States Government Technical Information Center	Contact NSPE Information Center

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