

3RD MIAMI INTERNATIONAL CONFERENCE ON ALTERNATIVE ENERGY SOURCES

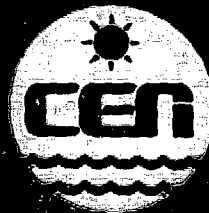
MASTER

15-17 December 1980
Miami Beach, Florida



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Clean Energy Research Institute
School of Engineering and Architecture
University of Miami, Coral Gables, Florida

Edited by

H. Hejat Veziröglü

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MASTER



Presented by:

Clean Energy Research Institute
School of Engineering and Architecture
University of Miami, Coral Gables, Florida

In cooperation with:

U.S. Department of Energy
International Association for Hydrogen Energy
International Atomic Energy Agency
International Solar Energy Society
International Association of Housing Science
Florida International University
Florida Solar Energy Center
Mechanical Engineering Department,
University of Miami

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We also wish to extend sincere appreciation to the Invited Lecturer, Eric A. Farber, University of Florida; to the Keynote Speaker, Harold Hanson, Office of the Honorable Don Fuqua, U.S. House of Representatives; and to the Banquet Speaker, Ned W. Dearborn, U.S. Department of Energy.

Special thanks are due to our authors and lecturers, who provided the substance of the Conference, as published in condensed form in the present Proceedings.

And last, but not least, our debt of gratitude is owed to the Session Chairpersons and Session Co-Chairpersons for the organization and execution of the technical sessions.

3rd Miami International Conference
on Alternative Energy Sources
Organizing Committee
October 1980

FOREWORD

Fossil fuels, particularly oil and gas, which presently provide most of our energy needs, are rapidly being depleted. Coal has been less rapidly utilized because it is less convenient and creates more environmental problems.

Alternative sources of energy are available but are relatively undeveloped technologically or not utilized fully. Some of these are renewable, such as solar heat, solar electricity, hydro, wind, ocean thermal, and salinity gradient energy. Others are depletable but relatively untapped, such as geothermal heat or synthetic fuels from coal or wastes. Nuclear energy as presently utilized depletes uranium more rapidly than energy from breeder reactors. Nuclear fusion is still a hope for the future. Hydrogen is a suitable synthetic fuel for many applications and has an unlimited raw material base — water. It requires the development of environmentally acceptable energy sources, preferably non-depleting, to produce it.

This Conference, as its successful predecessors, the 1st and 2nd Miami International Conferences on Alternative Energy Sources, addresses itself to all aspects of the alternative energy sources. It includes sessions on solar energy, ocean thermal energy, wind energy, hydro, nuclear breeders and nuclear fusion, synthetic fuels from coal or wastes, hydrogen production and uses, formulation of workable policies on energy use and energy conservation. A session on energy education is also included.

The overall objective of the Conference is to inform those who attend of the present state of the art and the rate of progress in each of the alternative energy forms. This will include the latest information on the status of alternative energy sources research, development and applications. A rational basis for identification of individual areas of alternative energy sources for further research and development will be established. Active participation by authors and listeners should provide the direction and stimulation for further research, development and policy formulations.

This volume of Proceedings presents the papers and lectures in a condensed format, grouped by subject matter under forty-two chapters corresponding to the technical sessions. It is expected that this document will serve as a concise reference volume covering the developments in the field of alternative energy sources.



T. Nejat Veziroğlu
Conference Chairman & Editor

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THE ROLE OF SOLAR ENERGY IN THE LONG TERM U.S. NATIONAL
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DEPARTMENT OF ENERGY THERMAL ENERGY STORAGE PROGRAM OVERVIEW

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EXTENDED ABSTRACT

The Thermal Energy Storage (TES) Program of the U.S. Department of Energy (DOE) promotes energy savings and fuel substitution by developing and helping to commercialize technologies for storing heat or cold with short investment payback periods as a cost goal. The sources of energy include industrial and utility waste heat as well as primary sources such as solar, geothermal, nuclear, and fossil fuels. The primary energy sink involved in the storage of "cold" is winter chilled air. The DOE Thermal Energy Storage Program emphasizes near-term (1980's) approaches to displacement of natural gas and oil, mid-term (1990's) approaches to increased energy conservation, and far-term (beyond 2000) development of energy storage and transport techniques which will allow use of renewable resources such as solar energy. The applications include seasonal storage for district heating and cooling; daily storage and chemical heat pumps for active or passive solar and for conventional heating and cooling; heat storage for solar thermal electric power generation; and storage for recovery of industrial or utility waste heat.

The program has a budget of \$17.1 million (M\$) for FY 1980 distributed as shown in Figure 1. Program management for policy, planning, and budget issues are provided by the Office of Advanced Conservation Technologies (ACT) within the Office of the Assistant Secretary for Conservation and Solar Energy. Detailed project management is provided by field organizations, including Pacific Northwest Laboratory (PNL) for seasonal storage, Oak Ridge National Laboratory (ORNL) for heating/cooling and waste heat recovery, Solar Energy Research Institute (SERI) for generic thermal energy storage research and assessments, Sandia Livermore Laboratory (SLL) for solar thermal applications, and Brookhaven National Laboratory (BNL) for chemical heat pumps. The program includes a diverse range of individual projects, from analytic studies of thermochemical pipelines and feasibility studies of the application of thermal energy storage to various industries, through bench-scale laboratory investigation of individual phase-change materials, to large-scale field testing of aquifer storage.

Approximately 40 percent of the total energy demand in the U.S. is used in industrial applications, and both energy savings and displacement of fossil fuels can result from the recovery of reject process heat from industry. The DOE program has identified 20 applications for industrial heat recovery with TES. Of these, six specific industries were selected for detailed study. Demonstration contracts have been let in the primary aluminum and food processing industries. It was determined that TES already exists in some pulp and paper plant., principally in Scandinavia, and experience of the existing units is being documented in a commercialization package and distributed to industry.

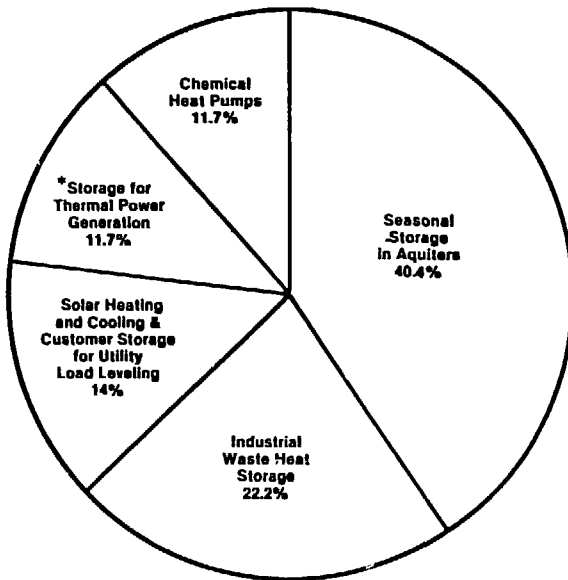
Seasonal storage of thermal energy in aquifers takes advantage of natural occurring, porous rock formations which contain large quantities of water. Experimental support work includes tests by Auburn University on storage in an aquifer at Mobile, Alabama and storage of chilled water at Texas A&M. DOE will be funding projects at three or four sites to demonstrate the application of aquifer thermal energy storage for district heating and cooling.

Heating and cooling of homes, offices, stores, and other buildings represents a large fraction of the U.S. national energy consumption. Part of the problem in this area concerns the peak electrical power demand in the day to heat or cool these buildings. Over a dozen utilities across the U.S. are currently involved in reducing peak-load electricity demand through storage of thermal energy from off-peak periods to on-peak times. To date, over 300 homes have customer side-of-the-meter storage in one form or another. In another part of this program, phase change materials have been developed to store "coldness" and are now commercially available. Two chemical heat pump concepts for building heating and cooling applications are the metal hydride system and the sulfuric acid/water heat pump. The two concepts are directed specifically towards waste heat recovery with eventual application using heat sources.

The development of solar-thermal electrical power involves coupling high-temperature solar collection technology to a thermal power cycle. A stable power supply also requires a thermal energy storage system capable of driving the power cycle during brief periods of cloud cover, during the night and during periods of inclement weather. Several thermal energy storage concepts are being developed for use with solar collectors cooled by water/steam, molten and liquid salt, liquid metal, gas, and organic heat transfer fluids.

Finally, generic research and development (RYD) activities include identification of thermal storage concepts for solar thermal applications, basic quantitative research to understand the hydrodynamic and heat transfer processes governing the operation of direct contact latent heat storage units, and establishing the feasibility of high temperature underground thermal storage of energy. Also included in the generic R&D area is the development of heat transport technologies.

**FY 1980
17.1 M \$ TOTAL**



*** Does Not Include \$3.5 M \$ Pass Through From Solar Thermal Power**

Thermal Energy Storage Program Funding by Application Area

SOLAR POND DEMONSTRATION —
DESIGN, CONSTRUCTION, OPERATION, TESTING

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ABSTRACT

Energy companies in the Sun Belt region can install solar ponds at existing power plant sites within their service area.

Solar ponds are the simplest technology available for thermal conversion of solar energy. The salt gradient solar pond was developed in Israel in the early 1960's where research has been rejuvenated recently by the escalation in oil prices. Solar pond research and development has been pursued in the United States since 1970 with one salt gradient pond now operating commercially in Ohio.

The basic technology is proven and the ponds are shown to be technically feasible and economically viable for many applications. Given an annual load profile and required output temperatures, a solar pond may be sized to meet temperatures and load requirements. Following a startup period ranging from one month to one year, the pond achieves "steady state" operation. The startup period is necessary to heat the pond water and the ground surrounding it.

The application of the energy drawn from the solar pond is limited to low-grade (less than 100 centigrade) energy conversion processes. For example, the solar - Rankine vapor compression refrigeration system and Absorption refrigeration systems. There may be some utilization of the heat in the solar pond for electric power production.

Technologies of low-grade heat utilization could be tested at the solar pond facility on a fee basis for the energy extracted from the solar pond.

This solar energy development could receive support of the state agency or the federal agency responsible for solar energy development.

The solar pond is suggested for power plant siting since it requires a start-up heat conditioning period of several months. This conditioning period could be shortened by using waste heat presently rejected from the power plant; also waste heat may be utilized in a combination solar/waste heat hybrid application.

The installation of a solar pond on the land available near a power plant would not preclude future use of the land for some other purpose. The pond would be a simple excavation with an earth berm plus some sort of water-tight liner to minimize seepage.

ABSTRACT

Laboratory Demonstration of Self-Generation Capability
of Saturated Solar Ponds

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The efficient utilization of solar energy depends upon the development of economical solar absorbers and converters. The solar pond is a promising candidate with a wide range of practical applications. The results of a number of recent studies show that a solar pond system is more economical for space heating and industrial process heating than conventional systems. Moreover, because of lower collector costs and "built-in" storage, solar pond systems can also be used for power generation.

The basic concept on which a solar pond system is based is that a non-convecting, transparent liquid pond in which the temperature increases with the depth can be established and maintained indefinitely. In a conventional unsaturated, salt stratified pond, because of diffusion of salt from the bottom to the top of the pond, it is necessary to wash the top layer of the pond with fresh water and to inject salt at the bottom of the pond continuously. The total amount of salt that would diffuse from the bottom to the top of a 1km x 1km pond is on the order of 30 metric tons/day. Thus, maintenance of proper salt-stratification in an unsaturated solar pond system is not very simple and can create operational problems.

The problem of pond mixing due to salt diffusion can be eliminated by utilizing a pond saturated with a solute, the solubility of which increases with temperature. Thus, for saturated salt ponds the need for removing salt from the pond surface and injecting salt at the bottom of the pond is eliminated. Compared to an unsaturated solar pond, a saturated salt pond, in principle, would be simpler in construction and operation. However, no such pond has been built so far because of the apparent lack of a solute that is cheap, stable, nontoxic, transparent, and available in large quantities, and has an average solubility which, over the pond temperature range of 20 to 100°C, is not too high.

InterTechnology/Solar Corporation has been working on salt-stratified solar ponds for the last four years. Experiments have been done on laboratory saturated solar ponds* using potassium nitrate, borax and disodium phosphate. A laboratory saturated pond experiment using potassium alum is planned for June 1980. The objective of this paper is to review the experimental results obtained on a laboratory potassium nitrate saturated solar pond. In particular, it will be demonstrated that the potassium nitrate saturated pond can be established, it can be regenerated after complete mixing, and it can sustain intermittent cooling and heating. Furthermore, it can maintain and correct stable density stratification by itself without any maintenance. The effect of 4-hour, 6-hour, and 8-hour intermittent heating and cooling cycles will be discussed. Some new applications of saturated solar ponds in addition to solar energy collection for process heat will also be discussed.

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PHASE CHANGE WITH RADIATION INTERACTION

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EXTENDED ABSTRACT

INTRODUCTION

Recently, phase change materials (PCM) are being considered for thermal energy storage applications in passive solar systems. Their high energy density and resulting savings in structural expenses and volumes make them particularly attractive. The potential for the use of PCM in such applications has been investigated both experimentally and theoretically [1][2][3][4][5]. Successful prediction of the performance of the units containing PCM requires accurate solution of the phase change problem, i.e. time domain solution of the melt front location and the temperature fields, in the liquid and solid regions. An excellent review of the available solution techniques is given in [6].

Some PCM such as paraffins, become semi-transparent when in liquid state and if subjected to irradiation through transparent boundaries, the analysis of the melt front propagation must take into account the disturbances in the temperature field for the liquid region and the effect of the radiation reaching the melt front and contributing directly to its propagation. One such solution is proposed in [7].

In the following sections, a one dimensional numerical scheme for the phase change with radiation interaction is described. The method is capable of handling time dependent convective boundary and irradiation conditions.

PROBLEM STATEMENT

Following the nomenclature shown in Fig. 1, the one dimensional phase change problem can be described by

$$g + k_s \frac{\partial T_s}{\partial x} - k_l \frac{\partial T_l}{\partial x} = \rho k \frac{ds}{dt}, \quad x = s, \quad t > 0 \quad (1)$$

$$\frac{\partial T_s}{\partial t} + \frac{\partial T_s}{\partial x} \frac{ds}{dt} = 0; \quad \frac{\partial T_l}{\partial t} + \frac{\partial T_l}{\partial x} \frac{ds}{dt} = 0, \quad x = s, \quad t > 0 \quad (2)-(3)$$

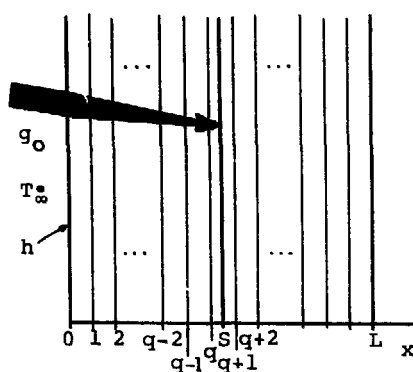


Figure 1. The nomenclature for the phase change problem with radiation interaction.

In the liquid region

$$\frac{\partial^2 T_l}{\partial x^2} - \frac{1}{k} \frac{dg}{dx} = \frac{1}{\alpha_l} \frac{\partial T_l}{\partial t} \quad (4)$$

with $g = g_0 e^{-\omega x}$. In the solid region

$$\frac{\partial^2 T_s}{\partial x^2} = \frac{1}{\alpha_s} \frac{\partial T_s}{\partial t} \quad (5)$$

$$\frac{\partial T}{\partial x} = \frac{h}{k} (T_w - T_\infty) \text{ at } x = 0 \quad (6)$$

$$\frac{\partial T}{\partial x} = 0, \quad x = L, \quad t > 0 \quad (7)$$

$$T = T(x) \text{ at } 0 \leq x \leq L; \quad t = 0 \quad (8)$$

Equations (4) and (5) are the temperature field expressions, (1), (2) and (3) are the interface conditions, (6) and (7) are boundary conditions and (8) is the initial condition. A finite difference solution technique is developed for the above problem similar to those utilized earlier by Goodman [8] and Lazaridis [9]. This approach calls for the solution of the field equations using standard finite difference techniques for the solid and liquid regions sufficiently away from the interface. In the neighborhood of the interface, the temperature profiles in the solid and liquid regions are expressed by second order polynomials given as

$$T_s = T_m + (x - S) \left. \frac{\partial T_s}{\partial x} \right|_S + \frac{(x - S)^2}{2} \left. \frac{\partial^2 T_s}{\partial x^2} \right|_S, \quad S \leq x \leq x_{q+2} \quad (9)$$

$$T_l = T_m - (S - x) \left. \frac{\partial T_l}{\partial x} \right|_S + \frac{(S - x)^2}{2} \left. \frac{\partial^2 T_l}{\partial x^2} \right|_S, \quad x_{q-1} \leq x \leq S \quad (10)$$

The solution of the field equation for the regions $0 \leq x \leq x_{q-1}$ (liquid) and $x_{q+2} \leq x \leq L$ (solid) at every time step, gives the temperatures T_{q-1} and T_{q+2} which are then substituted into (9) and (10) to give two equations with four unknowns, i.e. temperature derivatives at the interface. Two additional equations are obtained when equations (1) through (5) are combined by eliminating time derivatives and the interface velocity. These four equations are then solved to yield the temperature derivatives at the interface. The equation (1), (9) and (10) can now be readily evaluated for the interface velocity and T_q and T_{q+1} . The new location of the interface after a time step can be obtained by

$$S^{t+\Delta t} = S^t + \frac{dS}{dt} \Delta t$$

The procedure repeats itself for every time increment. Special attention, however, is needed until the interface is sufficiently away from the boundary, i.e. $S > x_3$.

NOMENCLATURE

g	strength of irradiation	T_l	temperature, liquid, °F
h	heat transfer coefficient	t	time, hr
k	thermal conductivity	x	coordinate, ft
L	thickness of the slab, ft	ω	extinction coefficient, 1/ft
S	melt front location, ft	ρ	density lbm/ft ³
T_s	temperature, solid, °F	κ	latent heat of fusion

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ANALYSIS OF CYLINDRICAL HEAT
EXCHANGER WITH PHASE-CHANGE MATERIALS

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EXTENDED ABSTRACT

INTRODUCTION

In the field of energy, there is an increasing emphasis on phase-change materials (PCM). Their relative inexpense and high energy density make them attractive candidates for energy storage and transfer, especially in applications such as solar energy and utility peak-load leveling. Many of these applications, however, require system geometries of a cylindrical nature (pipes, tubes, etc.), even though the analytical methods available to describe their thermal performance are few in number. In addition, these methods, with their restrictive boundary conditions, are either mathematically too complex for engineering purposes, or simplified to the point of solving a pseudo-phase-change problem far removed from the actual system itself [1]-[7].

This paper outlines an efficient numerical method for modelling one-dimensional heat conduction (including latent and sensible heat) around an internally-convected cylinder of PCM; which predicts both the melt-line location and temperature distributions as functions of time. The versatility of the routine is reflected in the fact that temperature-dependent properties and initial temperature distributions may be included, as well as time-varying boundary conditions. Time-dependent inlet fluid temperatures can also be handled, which represents the more realistic condition encountered with energy storage and transfer systems.

PROBLEM DESCRIPTION

Figure 1 depicts the geometry under consideration. The PCM-containing, hollow cylinder is divided into 'M' sections of equal length. The PCM within each section is then divided into 'N' constant-thickness, concentric, annular rings, subject to the following heat-conduction equations:

$$\frac{\partial^2 T_i}{\partial r^2} + \frac{1}{r} \frac{\partial T_i}{\partial r} = \frac{1}{\alpha_i} \frac{\partial T_i}{\partial t} \quad t > 0 \quad (1a,b)$$

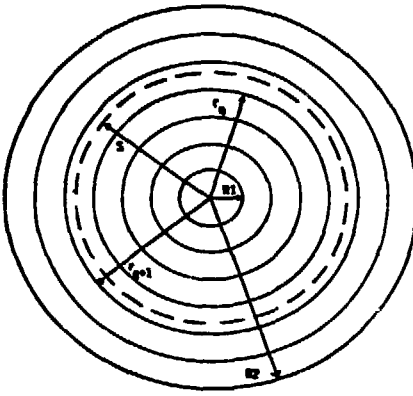


Figure 1. Cylinder axial view of concentric, PCM rings, with a particular melt-line location.

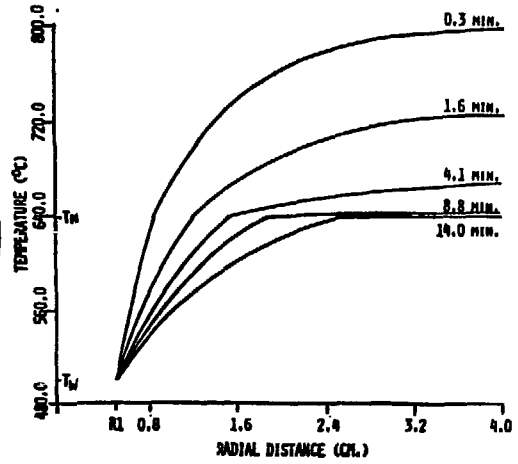


Figure 2. Radial temperature distribution within the first pipe section at five different times.

$$k_s \frac{\partial T_s}{\partial r} - k_l \frac{\partial T_l}{\partial r} = \rho L \frac{ds}{dt} ; T = T_m \quad r = s(t), t > 0 \quad (2)-(3)$$

$$\frac{\partial T_s}{\partial r} = \frac{h}{k_s} [T_w - T_\infty] \quad r = R_1 ; \quad \frac{\partial T_l}{\partial r} = 0 \quad r = R_2 \quad (4)-(5)$$

$$T_l = T_l(r) \quad t = 0 \quad (6)$$

where $i = s$ or l depending upon solid or liquid regimes. Equations (1a) and (1b) represent the temperature field equations; (2) and (3) apply to the interface, (4) and (5) are the boundary conditions and Equation (6) is the initial condition.

An explicit-type finite difference routine monitors the heat conduction in the regions two nodes away from the melt-front, while Taylor-Series expansions of the temperature are made within each of the two-node regions. Via these expansions, the temperature profiles near the interface are expressed as second order polynomials as in Equations (7a) and (7b)

$$T_i = T_M + (r - s) \left. \frac{\partial T_i}{\partial r} \right|_s + \frac{(r - s)^2}{2} \left. \frac{\partial^2 T_i}{\partial r^2} \right|_s \quad (7a,b)$$

where $r_{q-1} \leq r < S$ for $i = s$ and $S < r \leq r_{q+2}$ for $i = l$. Lazaridis [3] used a similar approach near the interface while Goodman [5] applied the equations over the entire liquid and solid regions which resulted in more restrictive boundary and time limitations. By using the method outlined above, the temperature gradients at the interface, and hence, the velocity of the fusion front are determined after each time step.

An energy balance on the volume of working fluid passing each node during the time step determines a new outlet bulk temperature, which in turn becomes the new inlet bulk temperature for the next downstream node. In this manner, by neglecting the relatively small axial heat conduction in the PCM and fluid, the melt-line position and temperature distributions within the cylindrical heat-exchanger can be modelled effectively. An example of the latter type of output is shown in Figure 2 for the case of solidification of a PCM with initial superheat, and data is presented for five different times. In addition to the above outputs, charging rates, heat-exchanger design optimization, as well as the contrasting of the thermal performance of several candidate phase-change materials are possible.

NOMENCLATURE

T	temperature	r	radial coordinate
t	time	s	distance to melt-line
T_M	melting temperature	T_w	wall temperature
T_∞	fluid temperature	h	heat-transfer coefficient
K	thermal conductivity	α	thermal diffusivity
ρ	density	L	latent heat
R_1	cylinder inner radius	R_2	cylinder outer radius

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SESSION 2A

SOLAR RADIATION AND THERMAL POWER

THE STOCHASTIC SUN: UNDERSTANDING THE INTERMITTENT RESOURCE

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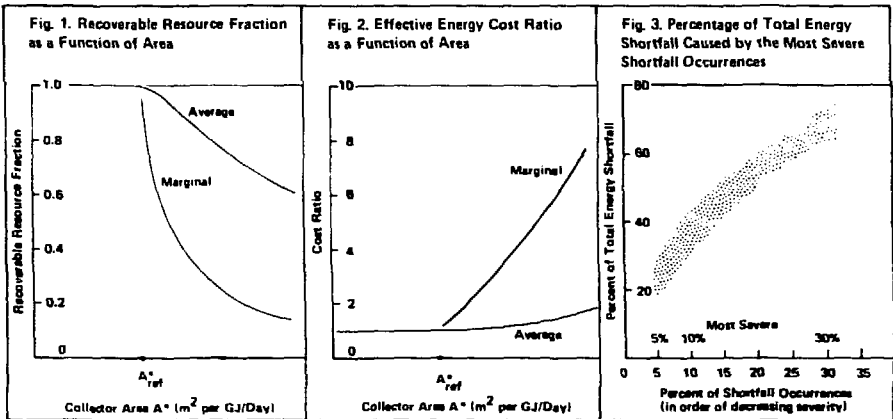
EXTENDED ABSTRACT

Intermittency represents the essential difference between an energy flux resource such as solar energy, whose incidence is beyond the user's control, and the stored energy resource of fuels. The stochastic or random character of solar variability accounts for much of the uncertainty, even controversy, about utilization and cost of the sun's energy. Present assessments of the solar resource account for intermittency only in its effect upon average value of incidence at a given location. Other research has emphasized enlarging the network of sites at which solar data are available and increasing the size and accuracy of the data base; however, there is still a gap between available data and the data requirements of users, especially for systems involving storage.

From the viewpoint of a designer of either solar energy systems or solar energy policy, four additional characteristics of resource intermittency--not now available--are of interest. First, a portion of total long-term insolation is not usable by most energy systems because it is not coincident with system demand; it is therefore useful to quantify the portion that can be used. Second, defining the sequential nature of sunny and cloudy periods is required to predict the performance of any system which includes storage. Third, characterizing the variability of the resource is necessary to define the confidence with which past data can be assumed to predict insolation in the future. Finally, an understanding of characteristics of variability which may be common to many locations is necessary to properly focus effort in collecting and disseminating solar energy data.

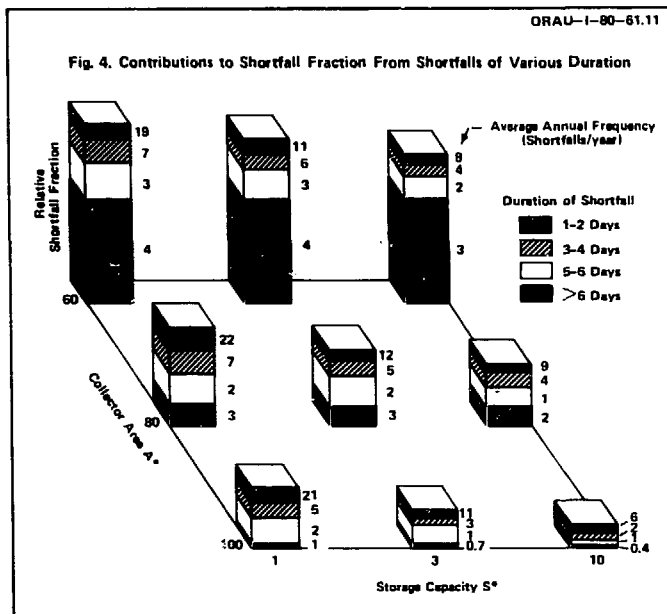
This paper discusses the concept of an ideal system as a device for determining the usable solar resource. The ideal system is defined in terms of a loss-free collector area A^* and storage capacity S^* per unit of system demand. The fraction of incident energy (termed "recoverable resource fraction") delivered by the ideal system represents an upper bound on the performance of any corresponding real system at the same location. The average recoverable fraction (for an entire collector) and the marginal recoverable fraction (for an incremental area addition) decrease as area increases beyond a critical value A_{ref}^* as shown in Figure 1. These decreasing returns in energy mean that the effective cost of delivered energy increases as investment in area increases. Figure 2 shows that average and marginal cost of energy increase significantly beyond A_{ref}^* . Adding storage would shift both curves to the right, but the same effects prevail. These variations are consistent for many diverse locations, but certain sites are shown to be distinctly different.

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The common use of the solar fraction (fraction of demand supplied by solar energy) as a predictive design tool has certain limitations. Among these is the lack of confidence limits on the prediction; the likelihood of small or large deviations from expected behavior is not known. We show that the ideal system is a vehicle for assessing deficiencies in energy supply with respect to the unit system demand. Distributions of frequency, duration, and severity of these energy deficiencies are illustrated; rare but lengthy shortfalls account for a surprisingly large portion of total energy shortfall. Figure 3 illustrates that the most severe 5 percent of shortfall events (two or three per year, on the average) account for about 25 percent of the total energy shortfall, the most severe 10 percent for 40 percent of the total, and the most severe 30 percent of the number for 60-70 percent of the total. For one typical site, in fact, the three worst shortfalls in a 15-year weather record (an average of one every five years) account for 7 percent of the total energy deficit. These characteristics are remarkably consistent among sites and are roughly independent of ideal system size—results for seven locations studied fall into the shaded band of Figure 3 over a wide range of area and storage sizes. It may be inferred that, on the basis of resource availability, systems are likely to perform considerably better than expected most of the time, and significantly worse on rare occasions. In predictive terms, closer confidence limits can be assigned to frequent events than to those that seldom occur, and the fine structure suggested is a useful tool in providing a clearer picture of day-to-day performance that may be expected from a system.

Total costs of using solar energy include possible costs of having reduced energy supply during the worst-case solar deficiencies, as well as capital and fuel costs.[1] Costs of reduced energy supply are likely to be dependent on frequency and duration of these shortfalls. Figure 4 shows that changes in area and storage have markedly different effects on shortfall frequency and duration. The bar heights represent shortfall fraction for a particular site for nine system sizes. Each segment indicates the



relative contribution of shortfalls of a particular duration, and the attached number denotes the average annual frequency of such shortfalls. The main effect of an area increase is to reduce the contribution of long shortfalls, with little effect on the shortest. On the other hand, storage size affects dramatically the number of shorter events. A system user who found extended shortfalls to be particularly costly would be led to install extra collector area to minimize total cost. Conversely, if frequent shortfalls were more troublesome, a user would be inclined to incorporate large storage capacity.

In conclusion, the ideal system and recoverable resource concepts are useful assessment tools to supplement present design and evaluation methods. They permit limitations imposed by resource intermittency to be separated from those arising from thermodynamic considerations of specific systems, and can be used to establish bounds on both cost and performance of solar energy systems.

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ABSTRACT

A simplified method of calculating the radiative field in solar ponds.

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The object of the present study is to obtain approximate relations to calculate the local volumetric absorption of solar radiation which explicitly appears as a heat source in the energy conservation equation for predicting the temperature distribution in ponds.

The physical model considers the pond as a one-dimensional layer bounded on top by the air-water interface and on the bottom by the water-soil interface; the former one can be considered as optically radiative smooth and its reflection and refraction characteristics have been predicted by means of the Fresnel and Snell relations of classical electromagnetic theory. The water is assumed homogeneous and isotropic, being able to absorb and not to scatter the solar radiation. At the temperature levels expected in ponds, the radiation emission is neglected, being the medium opaque in the infrared spectrum. The spectral behaviour of the volumetric absorption coefficient is modelled by means of a five values picket-fence scheme, while its temperature dependence is not considered because of the low temperature levels. The solar radiation intensity incident on the water surface is divided into the direct and diffuse components. Monthly averages of daily global solar radiation incident on an horizontal surface, as obtained by ordinary meteorological stations, are splitted into the hourly direct and diffuse component by means of the Liu and Jordan relations.

Numerical results for typical values of the pond depth ($L = 2 \div 3$ m) and of the bottom reflectivity ($\rho_b = 0.1 \div 0.3$), show that the diffuse solar component can be treated as if it had collapsed into an incident angle of 42° . For typical latitude values for Italy and different days of the year, the hourly local radiative flux due to the direct solar component is determined for clear day using the semiempirical correlation presented by Robinsons. Approximate relations are finally presented to predict the incident angle at which the daily direct solar radiation gives the same daily local flux.

ABSTRACT

THE NMSU SOLAR FURNACE FACILITY

by

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A solar furnace test facility has been built on the campus of New Mexico State University and is now operational. The facility is designed for long duration, high flux density, 0-85 W/cm², testing of materials. It consists of a 3.66 m by 4.27 m heliostat covered with 0.6 m-square mirrors mounted on a surplus 584 radar pedestal, a 3 m-square concentrator with small flat mirrors designed to focus on a test area 2.6 m from the center of the concentrator and an attenuator designed to vary the flux-density at the test area, Fig 1.

The heliostat reflecting surface is FEK-244 aluminized acrylic placed on the front surface of 0.6 cm plate glass and the concentrator facets are back-surfaced iron glass 6.3 cm-square and 0.3 cm thick. Heliostat tracking is accomplished by balancing photoconductive cells which trigger a drive pulse generator to the heliostat motor armatures.

The facility was built entirely with student labor and as a consequence is relatively inexpensive. Similar facilities can be constructed at other universities using similar techniques and utilizing the student labor resource. Besides the monetary benefits, students working on projects such as this are exposed to a valuable educational experience which will benefit them in their engineering careers.

The funds needed to complete this project were provided by Sandia National Laboratories, Albuquerque, New Mexico and the Mechanical Engineering Department at New Mexico State University and the space upon which it is located was donated by the Physical Science Laboratory at New Mexico State University.

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A second facility to be located just west of the 5kW_{th} furnace is being planned. This facility will be a 15kW_{th} solar furnace with a vertical beam. A 6.4 m diameter paraboloidal disk has been identified as the concentrator and the heliostat will be approximately 7.6 m by 8.8 m. A third reflecting surface will be used to divert the beam either vertically upward or downward depending on the test requirements. Flux densities up to 150 W/cm² are expected at the test plane.

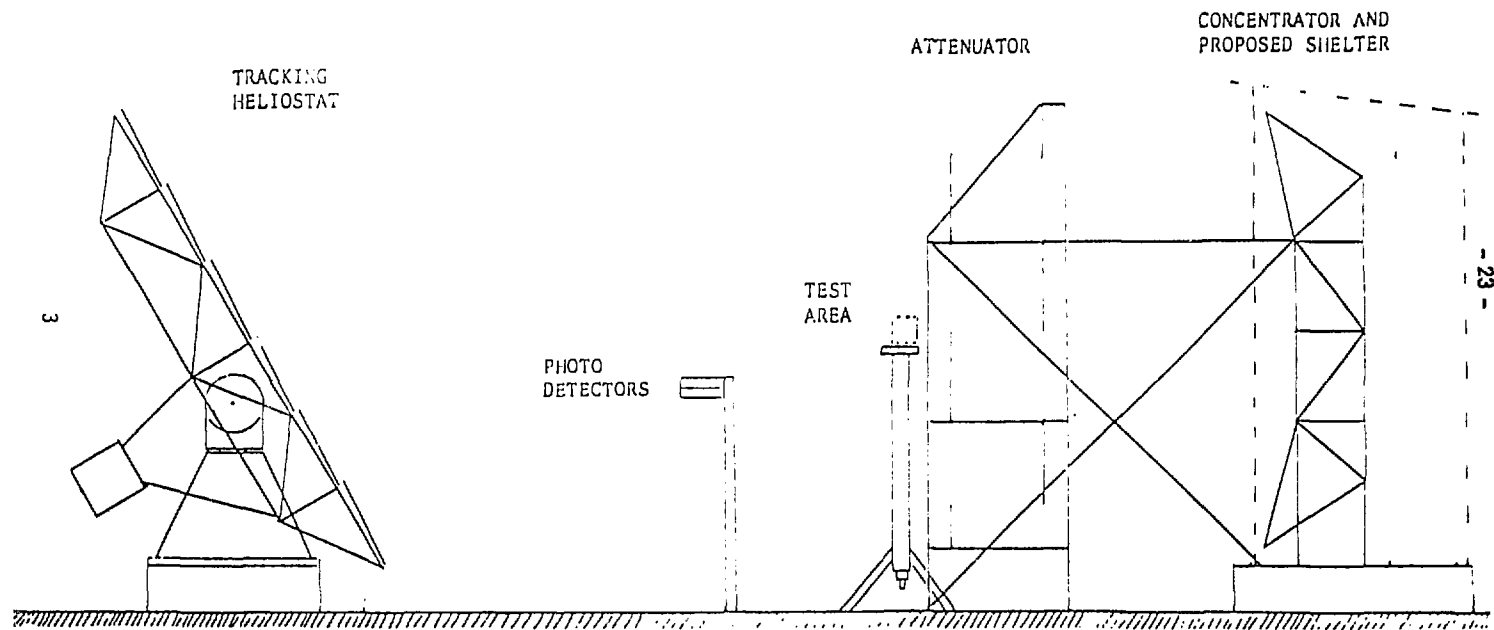


FIGURE 1 FACILITY SETUP

SOLAR THERMAL POWER GENERATION
- NET ENERGY ANALYSIS -

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EXTENDED ABSTRACT

1. INTRODUCTION

From an energetic point of view, the introduction to the market of a new energy supply system is only expedient if this system provides substantially more energy during its lifetime than was used for its construction and operation. In the case of solar power generation, there are occasional doubts whether this energy economy is given, among other things, in view of the high material expenditure for the collectors. It is the aim of this paper to determine the energy pay-back time of different solar thermal systems using known methods of net energy analysis, and to compare it with that of other power generation technologies.

2. METHOD OF NET ENERGY ANALYSIS

To ascertain the energy expenditure two different procedures are used, i.e. process chain analysis and input-output method /1/.

For the process chain analysis, the generally complex production process is broken down into a multitude of small transparent individual processes whose energy expenditure is analyzed and summed up. The result of such a chain is the energy expenditure for a given product. The following Table 1 shows some relevant examples for materials.

TABLE 1: Specific Primary Energy Expenditure for Various Materials according to /1/

Materials	kWh/t
Aluminium sheet, profiles	72500
Steel plates up to approx. 3 mm	9200
- above 3 mm	7780
Copper tubes, profiles	27000
Concrete	250
Roof tiles	530
Flat glass	6000

The second procedure, i.e. the energy input-output method, uses the input-output tables established for national accounting.

TABLE 2: Specific Primary Energy Expenditure of Selected Industries in the Federal Republic of Germany

Sector of the Economy	Primary Energy Expenditure (kWh/DM)
Mechanical engineering	1.7
Electrical engineering and optics	1.8
Iron, sheet metal, metal industry	2.5
Glass and fine ceramics	4.3

3. SOLAR THERMAL POWER STATION SYSTEMS CONSIDERED

Three representative power categories of solar thermal power stations are selected for net energy analysis: one minisystem of 10 kW, one 1 MW solar farm system and one solar tower system of 10 MW.

TABLE 3: Data of the Systems Considered

	Solar farm		Solar tower
Power output (MW)	0.01	1	100
Collector	flat plate coll.	parabolic trough	heliostat
Total weight of collectors (t)	34	827	44460
Annual electricity production (MWh)	37.2	3720	310000
Total efficiency (p.c.) (annual mean)	1.5	9.8	19.8
Max. temperature of working fluid (°C)	90	270	510
Collector surface (m²)	953	12720	521000
Storage capacity (kWh/d)	40	2000	-
Back-up system	-	-	hard coal
Specific plant costs (DM/kW _{e1})	35000	10700	4529 ²
Energy costs (solar) ¹ (DM/kWh)	1.60	0.49	0.248 ³
Number of plants produced per year	2600	85	2

¹ Energy costs for consumption at the site

² Solar section only

³ Solar only; when including the back-up system, 0.168 DM/kWh will result with hard coal costs of DM 200/tSKE

4. RESULTS

The two methods of net energy analysis, i.e. direct determination via material expenditure and indirect determination via input-output tables, were used in parallel, provided that relevant data were available. In each case, the determination of the energy pay-back time was based on the respective higher values of energy expenditure. The results are shown in the following Table 5.

TABLE 5: Results of Net Energy Analysis for Solar Thermal Power Stations

	Solar Farm 10 kW	Solar Farm 1 MW	Solar Tower 100 MW
Specific energy expenditure for the solar plant section (MWh/MWe1)	98100	18785	8871
Energy pay-back time (solar) (a)	8.8	2	0.95
Energy conservation (MWh)	$1.8 \cdot 10^3$	$257 \cdot 10^3$	$22366 \cdot 10^3$
Fuel equivalent for energy conservation	$0.155 \cdot 10^6$ liter diesel oil	$21.9 \cdot 10^6$ liter diesel oil	$2.74 \cdot 10^6$ tSKE

The following Table 6 compares the solar tower system with coal-fired and nuclear power stations.

TABLE 6: Comparison of the Energy Pay-back Time for Different Large-scale Commercial Power Generation Technologies /1/

Solar tower	100 MW	0.95 a
Coal-fired power station	100 MW	0.15 a
	1300 MW	0.08 a
Light-water reactor	1300 MW	0.33 a

Although the energy pay-back time of large-scale commercial solar systems is three times higher than that of light-water reactors and 6 to 11 times higher than that of coal-fired power stations, the low absolute value of approx. one year still is no argument against this technology.

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THERMAL AND OPTICAL CONSIDERATIONS OF THE
DISH-STIRLING ELECTRIC GENERATION SYSTEM

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EXTENDED ABSTRACT

This paper presents the results of optical and thermal assessments of the design parameters of solar concentrator/receiver combinations suitable for the Dish-Stirling electric generation. This system, which is presently under development, has been identified as having a high potential for providing electrical energy at a cost competitive with conventional energy sources. The general point-focus distribution Dish-Stirling system consists of (a) a paraboloidal dish, (b) a cavity-type solar receiver, (c) a Stirling engine to which the solar receiver is directly coupled and (d) an alternator to produce electricity.

The solar flux input at the receiver aperture is influenced by a number of factors affecting the optical performance of the solar concentrator. The factors include the geometric configuration of the optical design and the optical characteristics of the concentrator such as reflectance, slope errors and tracking errors, etc. The net thermal power collected by the receiver is determined by the flux distribution impinging on the receiver surfaces, the intercept factor, the effective emissivity and absorptivity of the receiver, and thermal losses due to conduction, convection and reradiation. The presentation of the results may be divided into two parts; namely, those for a general Dish-Stirling system and those for a specific system which is under development. For the general system, the optical and thermal assessment results and methodology are presented so that they can be utilized by engineers who are interested in the overall system design and system tradeoffs. They include the normalized flux distribution along planes at or behind the focal planes, the intercept factor as a function of the receiver aperture radius, concentrator quality considerations including slope errors characterized by radial and circumferential standard deviations, and simple engineering expressions for computing energy balance and heat loss.

The concentrator for the specific Dish-Stirling system under development at Jet Propulsion Laboratory is known as the Test Bed Concentrator. It consists of spherical mirror facets mounted to a paraboloidal

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substructure with a diameter of 11 m. At present the Test Bed Concentrator has been installed and is operational with a measured total thermal energy of 82 kW_t available at the focal plane. The Dish-Stirling Solar Receiver with fossil-fuel combustor (DSSR) has been designed by Fairchild Stratos Division and is being fabricated by Solar Turbines International. It is of the cavity type and the surface consists of a conical plate with integral passages for the helium working fluid. The Inconel 617 passages are imbedded in a copper matrix which is encapsulated in an Inconel 617 sheet. The Stirling engine to which the DSSR is coupled is a United Stirling P-40 engine modified for solar applications. The alternator is a 25-kW_e direct driven induction type alternator for the production of a 60 Hz 115/230-volt output. The detailed design of all the above components has been accomplished and fabrication is well under way. After fabrication, assembly and acceptance testing, the Dish-Stirling Electric Generation System will be tested at the Edwards Air Force Base near Lancaster, California where the insolation level is considered to be one of the best in the United States with excellent meteorological conditions. Representative results of extensive engineering analysis computations in the thermal and optical assessments are also presented for the above specific system.

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology and was sponsored by the U.S. Department of Energy through an agreement with NASA.

SOLAR REPOWERING OF FOSSIL PLANTS - AN EMERGING TECHNOLOGY

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The market for solar repowering has been assessed in several DOE sponsored studies, one devoted specifically to repowering, and the others to solar hybrid type of power plants. Since repowering can be considered to be a solar hybrid, the total potential market is the aggregate of plants which are possible candidates for repowering plus planned new plants in the time frame 1985 to 2000. In addition to solar repowering of fossil oil/gas fired power plants, a perceived large market exists for solar retrofit industrial facilities.

Studies to date have analyzed the repowering/retrofit market in terms of geographical area; namely, the southwest. The system discussed, solar central receiver, is generally limited to applications in the "sun belt" area, which spans the lower southern portion of the nation. Other systems, which can supply lower temperature and quantities of process heat, can be applied in areas with lower insolation.

Repowering a power plant entails switching the source of energy of an existing power plant from a fossil fuel to a more readily available and/or cheaper fuel. An existing plant can be fully repowered by the chosen substitute fuel, thereby, eliminating the original energy input source, or the plant can be partially repowered, with the new fuel providing part of the energy input to the power cycle or the two sources of fuel can coexist in parallel.

One of the most advantageous sources of energy for repowering is solar energy in a power generating facility with the central receiver concept. In this system, a field of heliostats (large mirrors used to reflect sun

light) track the sun across the sky during the day to maintain the optimum angle or incident sun light on the mirror of the heliostat. The sun light is reflected by all of the heliostats to a central receiver which is mounted atop a tower. The central receiver is cooled by a heat transfer medium which is pumped through the receiver absorbing the heat of the reflected sun light. The hot fluid flows to a heat exchanger where heat is transferred to the steam cycle working fluid, which is water. The heat exchanger in this case replaces the conventionally fueled boiler, bringing the cycle feed-water up to operating conditions. The cooled heat transfer fluid is then pumped back up to the receiver, completing the loop.

In order to make use of solar energy for repowering an existing power station, the environment must be suitable. Insolation levels must be high and fairly continuous throughout the year, large land area must be available for the heliostat field. For this reason, the southwest United States (Arizona, New Mexico, etc.) are best suited to solar energy repowering in U.S.A.

In order to study feasibility of the repowering plan above, the U.S. Department of Energy has sponsored a study performed by the team of Arizona Public Service Co., Gibbs & Hill, Inc., Martin Marietta Aerospace Corp., and Badger to furnish preliminary design for the repowering of the Arizona Public Service Saguaro power station. The existing plant consists of two oil-fossil fired units. Unit No. 1 will be repowered using a solar central receiver system. The Saguaro system employs a heat transfer fluid of molten salt (60% NaNO_3 and 40% KNO_3). 3.8 hours of thermal energy storage to be used for optimum dispatch of power to the utility system is provided. The heliostat field consists of 10,500 heliostats. Superheated steam is provided by the solar heat exchanger.

The repowering can be applied to industrial facilities as well. Any heavy user of thermal energy located in an adequate geographical area is a potential candidate.

EFFECTS OF THERMAL BUFFER STORAGE PERFORMANCE
ON PARABOLIC DISH SOLAR POWER SYSTEMS*

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EXTENDED ABSTRACT

INTRODUCTION

The basic module of a parabolic dish solar thermal power system consists of a sun-tracking paraboloidal collector, a solar receiver, a heat engine and an electric generator. The latter three components are located in the vicinity of the focal point of the collector. The performance of such a power system is highly susceptible to sudden changes in weather conditions. This high sensitivity is expected not only to affect system performance, but also to cause great system operation difficulties. A thermal storage unit integrated with a solar receiver is believed to alleviate these problems. However, an understanding of the effects of thermal storage on the system is required before a storage concept can be developed. An analytical study was, thus, made to ascertain the effects of such a subsystem on the performance of a parabolic dish solar thermal power system. This paper reports the preliminary results. The study is exploratory in nature. The main purpose is to identify the essential parameters affecting the performance of such a subsystem. For this reason, a simple lumped parameter approach was used. The storage material was limited to phase change material (PCM). Specifically, NaF-MgF₂ (66.9% - 33.1% by weight) eutectic salt mixture was chosen for this study. The buffer storage subsystem analyzed is suitable for a power module using a Stirling engine for the generation of electricity at a rate of about 25 kW for an insolation condition of 1.0 kW/m². The results include the effects of storage capacity on the subsystem efficiency, and on the transient behavior of the subsystem under different operating conditions such as start-up, shut-down, and short cloud passage. The effects of heat transfer enhancement in the PCM are also explored.

THERMAL MODEL AND ANALYSIS

The buffer storage subsystem under consideration is a simple cavity surrounded by PCM imbedded with heat transfer tubes for the extraction of heat stored in the PCM. The entire subsystem is surrounded by a layer of thermal insulation to minimize subsystem heat loss. Concentrated solar flux enters the cavity aperture, is absorbed by the cavity, and is then transferred to the

* The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the U.S. Department of Energy through an agreement with NASA.

PCM and into the fluid flowing in the heat transfer tubes for the operation of the engine. Heat is lost through the insulation and the cavity aperture.

A nodal thermal network was built based on this subsystem model, and the network was solved by the thermal analyzer computer program SINDA. In each case, the subsystem was heated from room temperature with an insolation of 1.0 kW/m^2 until it reached steady state. The insolation was then reduced to zero for the study of cooling phenomena. Several flowrates, storage capacities and different thermal conductances were analyzed. Temperatures, efficiencies, heat flows into PCM and fluid, and degree of melt and solidification were calculated.

PRELIMINARY RESULTS AND CONCLUSIONS

The results of the analysis are plotted in various forms as a function of the storage capacity or time, and are given in the paper. Preliminary conclusions from these results are presented below:

- (i) PCM thermal conductivity and interface thermal resistance are critical factors affecting the performance of a thermal buffer storage subsystem. These factors will affect receiver cavity temperature, subsystem heat extraction rates, thermal lag, and subsystem thermal efficiency. The effects become more severe as storage capacity increases.
- (ii) By heat transfer enhancement of the PCM, such as the use of fins, bulk additives, mini heat pipes, metallic meshes, screens or other materials, and by the increase of contact area with the PCM, the problems caused by the thermal barrier in PCM can be significantly alleviated.
- (iii) For the concept analyzed, the results indicate that, without heat transfer enhancement, the subsystem will not work satisfactorily with the configuration under consideration.
- (iv) The results also show that the fluid inlet conditions (temperature and flow rate) can affect the transient behavior of the subsystem.

A SOLAR THERMAL STEAM ELECTRIC POWER SYSTEM, BASED UPON MULTIPLE UNITS
OF A POLAR MOUNTED DUAL FOCUS SOLAR COLLECTOR AND ITS GROUND
LEVEL DUAL FOCUS SOLAR FURNACE

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EXTENDED ABSTRACT

The SOLAR POWER MOUNT and the SOLAR POWER HALF DISC are "sister" Equatorially Mounted sun tracking apparatuses in the Solar Thermal Steam Electric Power Systems category,---of megawatt potential when combined as multiple units.

Their innovative approaches to solar energy evolve from their adaptation to sun tracking of the principle of the Equatorial Mount used by astronomers to track celestial bodies.

This adaptation of the Equatorial Mount to sun tracking has been successful because of an ingenious combination of increments of one degree of lift by a hydraulic jack controlled by a synchronous electric time-switch clock programmed according to one degree of declination change as perceived in the Ephemeris Table (Apparent Declination Column) in the annual Nautical Almanac.

Because of the Equatorial Mount nature of its sun tracking, several new developments have evolved:

1. The SOLAR POWER HALF DISC can carry a 40 foot square solar collector as compared with a 25 foot square solar collector carried by the SOLAR POWER MOUNT.
2. A separate ground level wind and weather protection vault for each.
3. A constant down deflection to a ground level solar furnace from a flat solar collector with an arrangement of flat mirrors with a common focus. This ground level solar furnace will be the first of its kind in the United States.
4. A compact, four-in-one ground level solar furnace (solar furnace, steam turbine, electric generator, and dual, back-to-back solar-oil (or coal) furnace).

Because the SOLAR POWER MOUNT and the SOLAR POWER HALF DISC are complete, self-sufficient units, expansion of multiple units over an area have a megawatt potential of electric power production similar in many ways to the Solar Power Tower System.

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Other criteria of feasibility addressed are: tracking errors, manufacturability, structural analysis, materials compatibility, maintenance requirements, economic analysis, and use adaptations.

LATENT HEAT-OF-FUSION ENERGY STORAGE: EXPERIMENTS ON
HEAT TRANSFER DURING SOLID-LIQUID PHASE CHANGE

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INTRODUCTION

Commercial acceptance and the economics of solar energy, conservation, "waste" heat utilization, and other alternate energy technologies are tied to the design and development of efficient and cost effective thermal energy storage systems (TES). The latent heat-of-fusion energy storage concept has the important advantages of: (1) storing thermal energy at a nearly constant temperature and (2) a large specific storage capacity. Unfortunately, there is little information available on heat transfer coefficients, solid-liquid interface motion, and other technical data applicable to the design of latent heat-of-fusion TES systems especially under realistic operating conditions. A good understanding of the heat transfer processes involved is essential for predicting the storage system performance with accuracy and avoiding costly system overdesign.

The purpose of this paper is to report on recent heat transfer experiments with solid-liquid phase change and relevant to latent heat-of-fusion TES systems. Several different experimental arrangements have been employed in order to obtain basic data on solid-liquid interface motion and local heat transfer coefficients within TES systems employing paraffins and salt hydrates as phase change materials. Melting and freezing experiments were performed in test cells [1, 2] which simulated TES modules. The heat sources/sinks used were: (1) a horizontal cylinder, (2) an array of three cylinders, (3) finned cylinders, (4) horizontal plates facing up and down, and (5) vertical plates. Representative results for solid-liquid interface position, as well as heat transfer coefficients at the heat source/sink and at the interface, will be reported in the paper. Instantaneously averaged (over the heated surface) heat transfer coefficients will also be presented and compared with results for natural convection heat transfer from a bare and finned cylinder. In addition to the experimentation, analytical models were developed for predicting solid-liquid interface motion during the melting and solidification of a PCM (phase change material) around a horizontal cylinder and from a horizontal plate. Predictions based on these models will be compared with the experimental data. A detailed description of the experimental and analytical results will be included in the paper.

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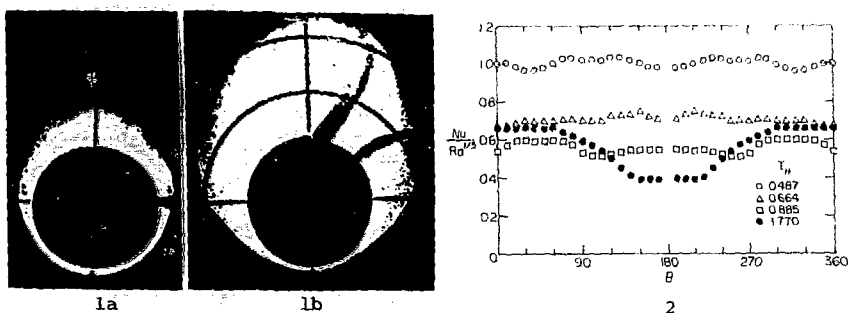


Fig. 1 Photographs illustrating the solid-liquid interface location during melting of n-Octadecane around a uniformly heated horizontal cylinder, $t = 80$ min: a) $Ste_H = 0.461$ and b) $Ste_H = 0.996$.
Fig. 2 Variation of local heat transfer during melting of n-Octadecane around a uniformly heated horizontal cylinder: $Ste_H = 0.461$ and $Ra = 1.2 \times 10^7$.

SELECTIVE RESULTS AND DISCUSSION

Selective results for solid-liquid interface motion and heat transfer during the melting and solidification of a PCM around a horizontal cylinder are included here as an example. The photographs in Fig. 1 show the instantaneous solid-liquid interface location during melting from a uniformly heated horizontal cylinder. It is clearly seen that at this time ($t=80$ min) the melting is not symmetrical about the axis of the cylinder (due to natural convection in the liquid). The thermal plume (in Fig. 1b) which originates near the top (about 20° to the right) produces nonsymmetrical melting about a vertical plane through the axis of the cylinder. Typical results for the local heat transfer coefficient around the heat source surface, presented in terms of conventional parameters, are shown in Fig. 2. At early dimensionless times ($\tau_H=0.487$) conduction is the dominant mechanism of heat transfer. Thus, the local Nusselt number is characteristic of that early time period and is practically uniform around the cylinder. As the melting continues and natural convection develops the Nusselt number variation becomes less uniform, reaching a minimum at the top of the cylinder.

A comparison between predicted and measured solid-liquid interface positions during melting from a uniformly heated cylinder is shown in Fig. 3. The results are given only for angular positions $0 \leq \theta \leq 180^\circ$ because in determining the local heat transfer coefficient at the interface it was assumed that the molten region was symmetrical about a vertical plane through the axis of the cylinder. The greatest discrepancy between the two results is in the vicinity of the upper stagnation point ($\theta=180^\circ$) where the arbitrary swaying of the thermal plume produced unsymmetrical melting during the experiments.

Fig. 4 shows a comparison between predicted and measured solidification

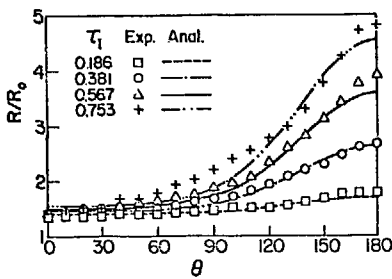


Fig. 3 Comparison of solid-liquid interface position during melting of n-Heptadecane around a horizontal cylinder for a constant surface heat flux: $Ste_H = 0.755$.

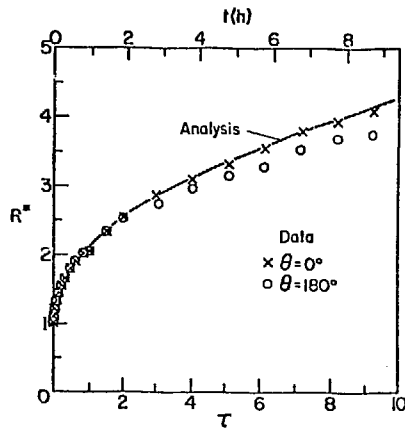


Fig. 4 Comparison of solid-liquid interface positions during solidification of n-Heptadecane around a horizontal cylinder maintained at constant surface temperature: $Ste = 0.176$.

front positions as a function of dimensionless time $\tau (=Fo \cdot Ste)$ during freezing around a cylindrical heat exchanger having a uniform surface temperature. There is good agreement between the data and the predictions at early times ($\tau < 2.0$). The difference between the predicted and measured solid layer thicknesses for $\tau > 2$ is attributed to both natural convection heat transfer and stratification of the liquid in the test cell.

CONCLUSIONS

The experimental results obtained demonstrate the importance of natural convection in solid-liquid phase change heat transfer under unstable conditions. The practice of neglecting the effects of buoyancy in the analysis of such problems does not appear to be reasonable. Natural convection has to be considered in the analysis of phase-change heat transfer in the design of latent heat-of-fusion TES systems if good agreement is to be obtained between predicted and measured solid-liquid interface position and system thermal performance.

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Moderate Temperature Thermal Energy Storage
with Phase Change Materials

by

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ABSTRACT

The heat transfer response of a dynamic phase change storage unit is described. The unit features two concentric cylinders with the inner one filled with phase change material and rotating on its horizontal axis.

Tests were carried out at three different rotational speeds; water was used as the heat transfer fluid. Three types of material, representing three major classifications of phase change materials, were studied: sodium sulfate decahydrate, P-116 and myristic acid.

A nucleating device attached to the inner cylinder was used to reduce the supercooling effects often encountered with phase change materials. The cylinder rotating action was observed to reduce the Glauber's salt segregation. Greater heat transfer rates were observed with Glauber's salt between the rotational speeds of 2.5 and 4.8 rpm. Tests with paraffins showed a lower heat transfer rate due to wall adhesion during solidification and to their low thermal conductivities. A cost analysis is presented to illustrate the economic feasibility of this system.

LOAD LEVELING VS LOAD SHIFTING APPLIED TO RESIDENTIAL
AIR CONDITIONING USING PHASE CHANGE THERMAL STORAGE MATERIALS

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EXTENDED ABSTRACT

INTRODUCTION

Storage assisted air conditioning is used to reduce peak power requirements. One system shifts the load entirely to off-peak hours by charging a bin containing thermal storage material at night and discharging the bin exclusively during the day for cooling. In load leveling, an air conditioner of one-half the nominal design capacity is used in parallel with a thermal storage bin also of one-half nominal design capacity. The bin is charged mostly, but not necessarily, at night during off-peak hours. During the day the two operate in parallel to supply the cooling load, the air conditioner going into the charging mode whenever the house demand is met.

THERMAL STORAGE

The thermal storage material[1,2] is a phase change salt mixture consisting mainly of Glauber's salt with additives to bring the transition temperature to 55°F. Its capacity is rated at 50 Btu/lb with an expected package life of 15 years.

The package is called the "Chub" because it is made on a commercial Chub machine[3] used extensively in food processing industries. Dimensions are 2'Dx20"L, wt. 3.25 lb, nominal capacity 162 Btu. Specially designed hardware allows stacking of Chubs in modules, dimensions of which are 20'x20'x20" containing 64 Chubs (see Fig. 1). Each module, therefore, has a capacity of 10,400 Btu. Modules may be stacked in flexible configurations to build up a storage bin space suitable to the individual application.

MODELS

The houses used for the demonstration program were provided by Delmarva Power & Light Co. and Long Island Lighting Co. They were very similar in character and construction, requiring 2-1/2 - 3-ton capacity units for air conditioning.

The load shift installation used a 3-ton compressor and 300,000 Btu capacity bin. The load leveling installation used 1-1/2-ton compressor and 180,000 Btu capacity bin. In the former, the peak kW demand was zero, whereas in the latter the kW demand was approximately uniform over 24 hours at one-half the value of the peak demand.

Schematic Diagrams of both systems are shown in Figures 2 and 3, together with the control functions. In both cases, provision is made for preferentially cooling the house during the off-peak period by direct air conditioning, if required. When the house temperature is satisfied, the system reverts to the bin charging mode.

Both systems were installed in the summer of '80 and after debugging (control relays, recording data, damper operation, etc.) have shown their capability to function as designed. Reliability, efficiency and economic data will be gathered during a full season of operation in 1981.

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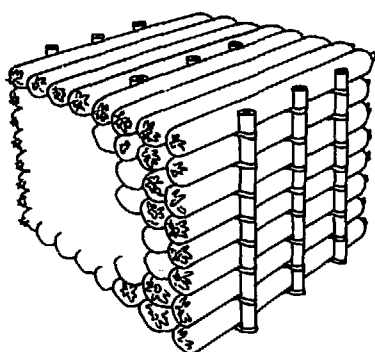
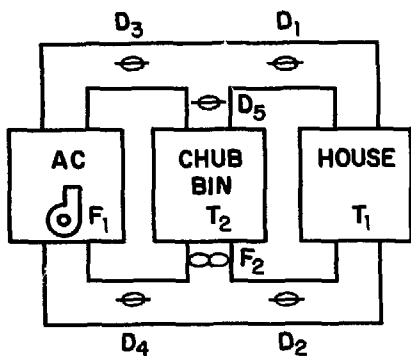
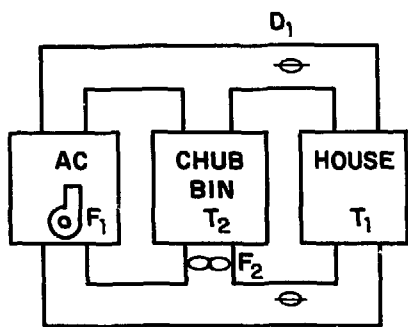


Figure 1. CHUB MODULE



	T ₁	T ₂	D ₁	D ₂	D ₃	D ₄	D ₅	F ₁	F ₂
DAY >78°	--	0	0	C	C	0	0	O _F	ON
DAY <78°	--	0	0	C	C	0	0	O _F	O _F
NIGHT >78°	--	0	0	0	0	C	ON	O _F	
NGT. <78° >50°	C	C	0	0	0	ON	O _F		
NGT. <78° <50°	C	C	0	0	0	O _F	O _F		

Figure 2. LOAD SHIFT



T ₁	T ₂	D ₁	D ₂	F ₁	F ₂
>78°	--	0	0	ON	ON
<78° >50°	C	C	ON	OFF	
<78° <50°	C	C	OFF	OFF	

Figure 3. LOAD LEVEL

CALORIMETRIC TESTING OF IMPROVED GLAUBER'S SALT FORMULATIONS

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EXTENDED ABSTRACT

INTRODUCTION

Recently, an understanding of the reasons for the decline in thermal energy storage capacity [1,2] with thermal cycling of thickened [3] Glauber's salt mixtures has enabled workers at the Institute of Energy Conversion (IEC) to develop improved formulations for the 90°F phase change thermal energy storage material. As a result, mixtures have been prepared which store thermal energy at a high level even after as many as one thousand thermal cycles. In this paper we will discuss the mechanisms responsible for the decline in performance with cycling of the original formulation, the steps which have been taken to solve this problem and present some experimental data on the improved formulations' performance with thermal cycling.

RESULTS AND DISCUSSION

Due to its incongruent melting, pure Glauber's salt's ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$) thermal energy storage (TES) capacity decreases with thermal cycling (Figure 1) [4]. Telkes [3] reasoned that if the anhydrous sodium sulfate (Na_2SO_4), which precipitates when Glauber's salt melts, could be uniformly suspended in the melt solution; then the TES capacity with cycling would be improved. As is seen in Figure 1, the use of attapulgite clay as a thickener improves the TES capacity significantly, however, the mixture is performing at about 50% of its ideal value after more than 1,000 cycles.

An analysis of the mechanisms responsible for the decline of the thickened material with cycling has led to two conclusions [2]: the size of the crystals increases with cycling and the thickening agent's effectiveness decreases with cycling. Therefore, an additive which would prevent formation of large crystals should improve the performance of the system with cycling. Also, a thickening agent that forms a strong gel would also help, provided the gel is strong enough to prevent the growth of large crystals. Figure 1 shows data for samples prepared with a crystal habit modifier and a new thickener as a function of thermal cycling. The data indicate a significant increase in performance with cycling.

Subsequent research has uncovered an additional crystal habit modifier which also significantly improves the performance with cycling of the Glauber's salt mixture. Table 1 lists the results, in cal/g of energy stored as the latent heat of fusion at 32°C (90°F), for the two crystal habit modifiers currently being studied in mixtures containing the attapulgite clay and the new thickener.

TABLE 1

Thickener: Attapulgite Clay - Ideal Value 49-53 cal/g		
Cycles	Habit Modifier #1 ^[5]	Habit Modifier #2 ^[5] (New)
0	54.4	45.7
50	42.9	45.2
100	43.8	41.8
200	42.0	40.5
Thickener: New Thickener ^[5] - Ideal Value 56-57 cal/g		
0	46.7	49.2
50	41.7	46.2
100	45.4	46.9
200	47.9	50.7

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SOLAR ENERGY STORAGE BY NATURAL ZEOLITES.
I. DEHYDRATION OF ZEOLITIC TUFF.

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EXTENDED ABSTRACT

INTRODUCTION

The adsorption process is a suitable solar energy storage system [1,2]. Such a process is in fact exothermic, so that, if an adsorbent, "activated" by heating, is cooled in presence of an adsorbable vapour, an amount of heat, comprehensive of sensible and adsorption heat, is released.

Among the various adsorbents, zeolites, framework silicates -characterized by structures with cavities and channels, normally filled with water, which can be reversibly and continuously removed- seem preferable because of the peculiar feature of adsorbing water vapour almost independently of environmental pressure [3,4].

On the ground of preliminary encouraging results [5], it was thought worthwhile to evaluate the possibility of using natural zeolites, namely zeolitic tuffs, which are pyroclastic rocks of large diffusion and low cost, as adsorbing materials in the solar energy technology.

The data here presented deal with the study of the water desorption of two zeolitic tuffs, one containing chabazite and another mainly phillipsite over chabazite, which are the two normal occurrences of these rocks.

RESULTS AND DISCUSSION

The samples of chabazite and phillipsite tuff contained about 80% and 65% zeolite, respectively. Water loss, evaluated on powdered specimens via

thermogravimetric analysis, was about 16.70% for the former sample and 12.50% for the latter.

Adsorption isotherms, determined in the range 20-80°C - useful for solar energy collection without concentrators - gave the possibility to calculate, by applying the Clausius-Clapeyron equation, the isosteric heat of adsorption. This value is close to 13 Kcal/mole of water for both tuffs.

Referring to chabazite tuff, by considering the specific heat of the tuff matrix (0.26 cal/g°C), the water loss in the range 20-80°C (~4%) and the apparent density of the rock (1.4 g/cm³), one can calculate the total volumetric heat capacity of the tuff, which is about 64 cal/cm³ [5] .

To evaluate the influence of the cation on the amount of water adsorbed, both tuffs were exchanged for Li⁺, Na⁺, K⁺ and Ca⁺⁺. For each of these cationic forms the curves of isothermal water loss at different temperatures in the range 20-400°C were determined. The curve represented in the Fig.1 gives the trend of the isothermal water loss, as a function of the temperature for the chabazite tuff without any exchange. It can be noticed that the total water content can be desorbed at about 250°C, which is a temperature easily obtainable with solar concentrators.

In the TABLE I the total amount of water desorbed by the samples in the various cationic forms is reported.

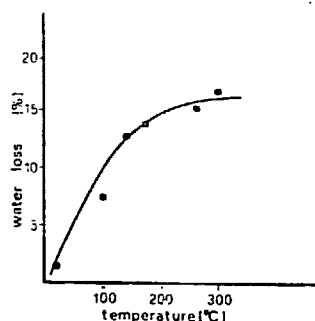


Fig.1 - Isothermal water loss vs. temperature for chabazite tuff without any exchange.

TABLE I
WATER DESORBED BY VARIOUS CATION EXCHANGED TUFFS

chabazite tuff		phillipsite tuff	
cation	water desorbed %	cation	water desorbed %
no exchange	16.70	no exchange	12.50
Li ⁺	17.05	Li ⁺	11.85
Na ⁺	16.18	Na ⁺	12.75
K ⁺	14.20	K ⁺	10.18
Ca ⁺⁺	17.05	Ca ⁺⁺	12.25

The desorption times are obviously function of the temperature and of the heating rate of the device. If the programmed temperature is rapidly reached (few minutes), the desorption times are of the order of 1+3 hours. For an example the chabazite tuff is almost completely dehydrated at 250°C in about 2 hours.

CONCLUSION

The results above summarized indicate that:

- (i) the adsorption properties of the two natural zeolites towards water vapour, in the limits of their application in the solar energy exploitation, are comparable, even if the chabazite tuff seem preferable for its higher zeolite content;
- (ii) cation exchange does not appear advantageous in increasing sharply the adsorption capacity;
- (iii) an almost complete water desorption can be achieved in few hours by heating the tuff at temperatures not higher than 250°C.

In conclusion zeolitic tuff can be considered an attractive material in energy storage for its low cost, large diffusion, high heat density and complete reversibility in charge-discharge cycles. The dry air, flowing out from such a store, is suitable for drying processes as further application.

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THERMAL STORAGE OF A PHASE CHANGE MATERIAL IN A
HORIZONTAL CYLINDER

by

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EXTENDED ABSTRACT

A two-dimensional mathematical model developed investigates the gravitational effect on the shape and location of the solid-liquid interface for a system within a horizontal cylindrical enclosure. The melting process within the enclosure is modeled for the three cases of (a) constant wall temperature (b) constant heat flux, and (c) constant heat transfer coefficient maintained at the tube surface. The complete solution for this model is included the transient temperature distribution and the location of the solid-liquid melt line for either the surface conditions considered.

The numerical method of finite difference is used to solve the system of governing equations. A variable transformation is successfully applied to handle the movement of the interface in the computations. In the solution of the energy equation, the implicit alternating direction technique is implemented.

The comparisons are made with the existing one-dimensional models. It is demonstrated that the use of the one-dimensional model to represent the behavior of the phase change process within a horizontal cylindrical enclosure, would produce consistently low estimates of the energy stored during a particular cycle. The results obtained from the two-dimensional model are significantly higher (depending on Stefan number) than those obtained from the corresponding one-dimensional models. This will provide valuable information to the thermal storage designer, since it will allow a more realistic evaluation of the capacity and performance of a system.

To complete the analysis, several experimental tests were performed to provide insight into the physics of the motion of the solid. A circular cylindrical tube is filled with a paraffin (n-Octadecane wax) and heated electrically in order to simulate the condition of the constant heat flux maintained at the tube surface. Experimental runs were made for varying heating rates and the data was recorded at regular time intervals. It is observed that the solid phase of the material always maintained a stable position at the bottom of the cylinder. That is, the solid mass underwent a continuous readjustment to a position that was anti-symmetric with respect to the axis of the tube. This information is adapted in the foregoing two-dimensional mathematical model.

1. INTRODUCTION

There are several situations in engineering in which the transfer of heat is accompanied by a change in phase in the conducting material. Some typical examples are, solidification and melting of metals in casting processes, chemical reactions such as combustion, the penetration of frost into the earth, and the ablation of materials on spacecraft re-entering the earth's atmosphere. These systems all possess an interface which separates the two regions of totally different thermophysical properties. At the interface, energy may be either liberated or absorbed; and the movement of the interface is some function of time directly dependent upon the conduction of this energy from one phase to the other. This condition imposes a nonlinearity in the heat conduction problem which makes the solution considerable more difficult. It is perhaps for this reason, that problems of this type have received comparatively little attention in the literature.

In this work, a mathematical model is formulated to describe the heat transfer process for a system in which the density of the solid is greater than that of the liquid. This model accounts for the fact that the solid melts in a configuration that is anti-symmetric with respect to the axis of the cylinder. Thus the interfacial position is calculated as a function of angular orientation as well as time. It is hypothesized that the force of gravity requires the solid to drop as it melts and maintain its anti-symmetric position throughout the melting process. This hypothesis is positively confirmed with thorough experimental investigation of the melting characteristics for a range of Stefan numbers.

2. ANALYSIS

The melting process within a horizontal cylindrical tube is modeled for the three limiting cases of (a) constant wall temperature (b) constant heat flux, and (c) constant heat transfer coefficient maintained at the tube surface. Of necessity, the complete solution for this model must include the transient temperature distribution and the location of the solid-liquid melt line for either of the surface conditions considered.

The model presented will be described by a cylindrical coordinate system the origin of which is located at the geometric center of the tube. Initially, the phase change material completely fills the enclosure. As the tube is heated, the material melts into some arbitrary shape (not necessarily circular) and the system then consists of both a solid and a liquid phase. The surface separating the two media, hence forth referred to as the interface, is located with respect to the origin.

It is intended that the model developed in this work will be representative of those materials for which the liquid phase is incompressible and the thermal properties within each phase are uniform. These materials should, in addition, melt congruently, that is, they should possess only one smooth, definite interface which is tacitly assumed to be an isothermal surface at the saturation temperature. This analysis idealizes the actual physical process in that it incorporates the assumptions that the solid phase remains at the saturation temperature throughout the melting process, and that the net rate of energy transport by convection in the liquid phase is negligible.

Several experimental tests were performed to provide insight into the physics of the motion of the solid. Experimental runs were made for varying heating rates and the data was recorded at regular time intervals. The results clearly show that there is a gradual and steady downward movement of the solid in the direction of the gravitational force. Experimental test show that regardless of the melting rates or boundary conditions imposed on the system, the solid medium always seeks to maintain a stable resting position at the base of the cylinder. This entire process of the repositioning of the solid is so gradual that it is barely discernable.

A comparison is made between the finite difference technique and Megerlin's method [1] for a one dimensional cylindrical system. The results show that the error incurred in the Megerlin method is proportional to the heating rates imposed on the system. And for any specific Stefan number, this deviation from the finite difference solution becomes gradually more pronounced as time (Fourier number) increases. These two conditions can, of course, be related back to the nature of the approximation. For slow heating rates (i.e. low heat fluxes or low temperature differences, the use of a profile which satisfies the energy equation only at the interface, is a reasonable approximation since the temperature distribution in the liquid is relatively uniform and there are no steep gradients. However, for the higher Stefan numbers a greater amount of energy is stored within a given period of time. Thus it can no longer be assumed that the temperature distribution in the neighborhood of the interface is representative of the entire liquid medium. Consequently it should be expected that the closest agreement between the two solutions occurs at low Stefan number during early stages of melting.

The values of the interface position are represented as a function of angle for various values of the Fourier number. Results from the computer program are restricted to the times from the commencement of melting up to the moment that the solid melts past the center of the tube. As the Ste is increased, the melting rate is accelerated. As expected, it was observed that for a given Ste , the constant wall temperature boundary condition presented here provides a much faster melting rate than the constant heat flux condition [2].

The rate of heat transfer at the wall and the total energy stored for the constant heat transfer coefficient thermal energy storage system are presented. The curves are parameterized by values of the Biot number. The results indicate that as Bi increases, the time variation of $\dot{Q}_L$ is more pronounced and thus the total energy stored, Q_L is greater.

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PCM THERMAL ENERGY RELEASE IN CYLINDRICAL
CONTAINERS OF VARIOUS CONFIGURATIONS

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EXTENDED ABSTRACT

Measurements were made of the rate of heat release during the freezing of a phase change material (PCM) enclosed in single, thin-walled copper cylinders. The thermal properties of the PCM, a commercially available paraffin wax (Parowax, an Esso product), were obtained using a Perkin-Elmer DSC-1 Differential Scanning Calorimeter. These results have been reported in a previous paper. (1)

The container shapes studied included three lengths each of plain circular, plain square and internally partitioned tubes. These tubes were insulated at the bottom and placed inside a larger tube to form a concentric double pipe heat exchanger. Water at inlet temperatures of 20 °C and 30 °C flowed co-axially through the annulus during these freezing runs. The experimental apparatus was similar to that described in (1).

The time variation of the rate of heat release was obtained by recording the outlet water temperature and making a heat balance. The liquid wax was initially at 70 °C or at a temperature just above its melting point (≈52 °C). The effects of the following parameters on the rate of heat release were studied (1) outside water temperature, (2) initial wax temperature (superheat), (3) shape of the container, (4) height of the PCM column in the container, (5) addition of metal inserts, (6) use of transverse (horizontal partitions). A few typical results are shown in Figures 1 through 6.

The heat transfer measurements reveal that conduction is the dominant phenomenon governing the heat flux variation with time during freezing. These measurements were then compared with a simple one dimensional pure conduction model. The small discrepancy between theory and measurements is probably due to the fact that the one dimensional model does not fit the actual geometry exactly. The insertion of metal springs to increase the effective conductivity of the solid wax does not increase the freezing rate to any great extent. Metal partitions which provide a conduction path from the outside tube wall into the wax, are much more effective.

The implication of these results for the design of a shell-and-tube PCM storage heat exchanger will be discussed.

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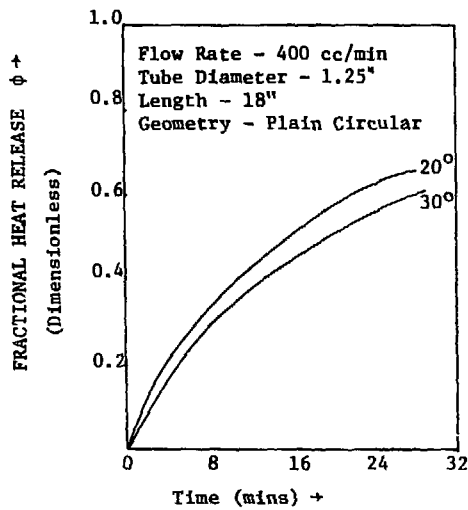


Figure 1 EFFECT OF THE INLET TEMPERATURE OF THE OUTSIDE HEAT TRANSFER FLUID ON THE HEAT RELEASE RATE.

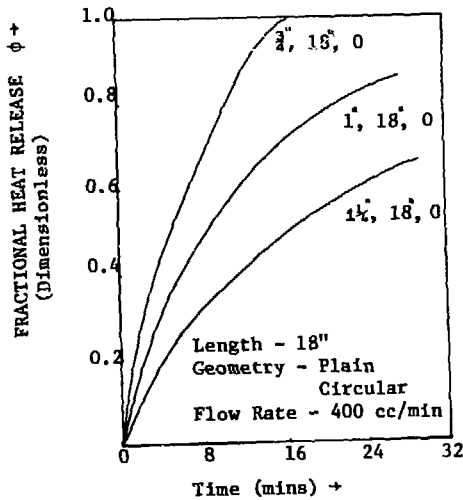


Figure 2 EFFECT OF DIAMETER ON THE HEAT RELEASE RATE FOR TUBES OF CONSTANT LENGTH AND GEOMETRY

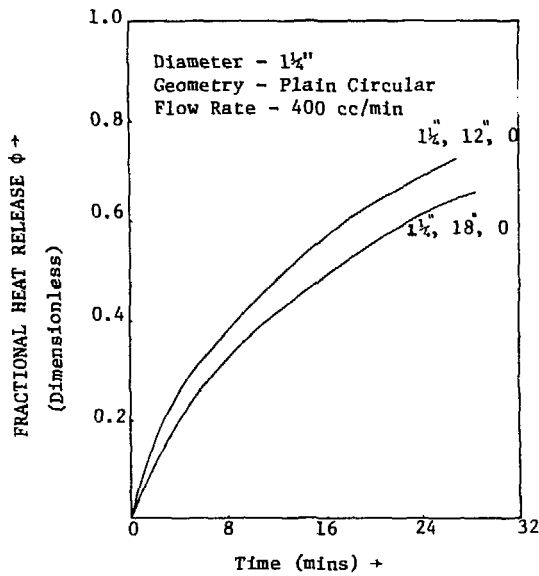


Figure 3 EFFECT OF LENGTH ON HEAT RELEASE
 FOR TUBES OF FIXED DIAMETER AND GEOMETRY

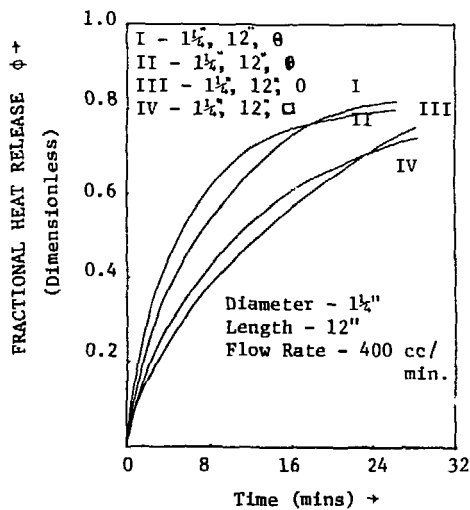


Figure 4 EFFECT OF GEOMETRY ON
 HEAT RELEASE FOR TUBES OF FIXED
 LENGTH AND DIAMETER

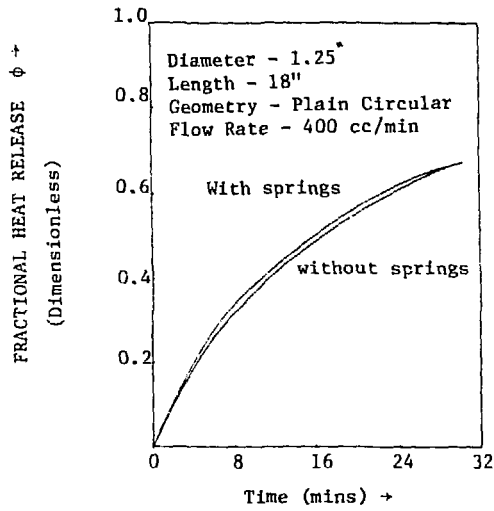


Figure 5 EFFECT OF ADDING HIGHER THERMAL CONDUCTIVITY MATERIAL (STAINLESS STEEL SPRINGS) TO FREEZING WAX

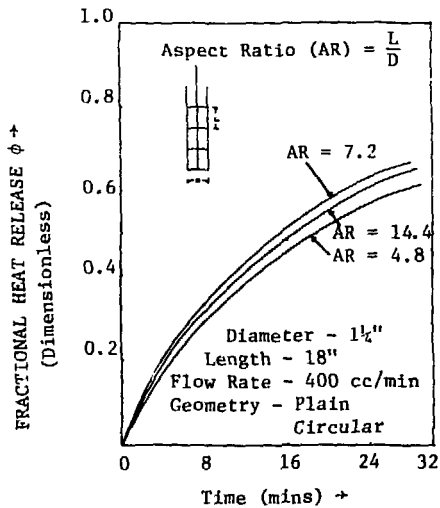


Figure 6 EFFECT OF TRANSVERSE PARTITIONS ON THE HEAT RELEASE RATE

Figures 1 through 6 show the effects of the following parameters on the cumulative heat released up to time t .

- a. Inlet temperature of cooling medium
- b. Diameter of the container
- c. Length of the PCM column
- d. Geometry of the container
- e. Addition of metallic springs to the PCM
- f. Transverse partitions

The amount of heat released is represented as ϕ , the fraction of the maximum possible amount of heat that can be released when the freezing is complete and the wax is supercooled to the temperature of the outside cooling medium. In figure 4 the symbols $\emptyset$ and Φ represent circular cylinders with one and two partitions respectively.

The implication of these results for the design of a shell-and-tube PCM storage heat exchanger will be discussed.

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SESSION 4A

SOLAR COLLECTORS

COMPARATIVE PERFORMANCE CHARACTERISTICS OF SOLAR COLLECTORS
WITH DEEP-TEXTURED AND PLAIN FLAT PLATES

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ABSTRACT

Investigations have been carried out to study the comparative performance characteristics of a flat plate solar collector with deep textured and plain collector surfaces. The results obtained show that the deep textured surfaces consistently enhance the collector efficiencies under various air flow rates and collector orientations. Three combined effects are responsible for the observed improvement of the collector performance. They are: increased collector surface area, enhanced heat transfer coefficient due to early turbulence promotion, and higher net absorptance via multiple-reflections in the deep textured surface valleys.

A twin solar collector system was designed and constructed which houses two flat plate collectors side by side, one with a textured surface and another with a plain surface. Due to the unique integral design, both collectors were placed under identical operational conditions throughout the experimental runs. Each collector unit is 17 inches wide and 77 inches long, yielding collector surfaces of 9.09 square feet each. Air flow rates ranging from as low as 5SCFM (0.55 SCFM/FT^2) up to 20SCFM (2.20 SCFM/FT^2) were employed. The black finished collector surfaces are both 24 gauge stainless steel plates supplied by Rigidized Metals Corporation (plain pattern and deep textured pattern, 6WL, non-prime side). The flow area cross section for air is $3/4$ inches high and 17 inches wide. The flow cross section, therefore, is 0.088 ft^2 . Figure 1 shows the schematics of the overall experimental setup.

As may be seen from Figure 2, the exit air temperature from the deep textured absorber plate is consistently higher than the exit temperature from a plain absorber surface. In comparing the heat removal rates from the collector surface, the product of overall heat transfer coefficient, U , and the heat transfer area, A , is important. As the flow rate increases within a laminar flow region, the increase of U is approximately proportional to the cubic root of the flow rate. In this region, the increased surface area A due to textured collector surface is a controlling factor which yields higher collector efficiency. See Figure 3 which shows the collector efficiency as a function of airflow rate for both plates. As the flow rate is increased, however, early onset of turbulent flow is promoted via the deep-textured plate surface. The quantity, U , starts to assume a controlling role, and eventually reaches a range where it is proportional to 0.8th power of the flow rate. The transition from laminar to turbulent region is desensitized due to the random surface conditions, and thus the transition is gradual. Since the relative increase of collector surface area, A , stays approximately constant in this region, the further increase in collector efficiency is mostly due to the enhanced turbulent effect. See Figure 4, which shows normalized differential efficiency, or relative efficiency change, $\Delta\eta/\eta$ as a function of air flow rate. Additional test runs subsequently showed that the general trend observed in Run S-7 prevailed, regardless of the varying collector orientations. A properly designed deep textured solar collector surface is also expected to give superior net absorptance due to its multi-reflective surface absorption, further improving the overall performance over a plain flat plate collector.

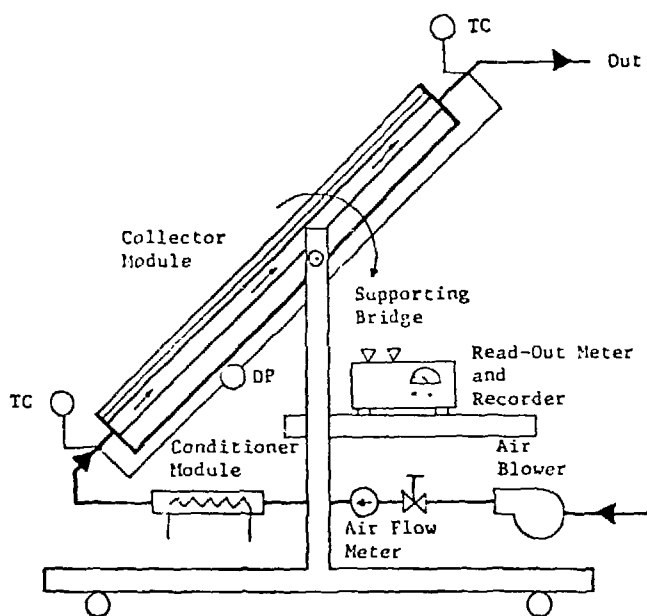


Figure 1. Test Apparatus.

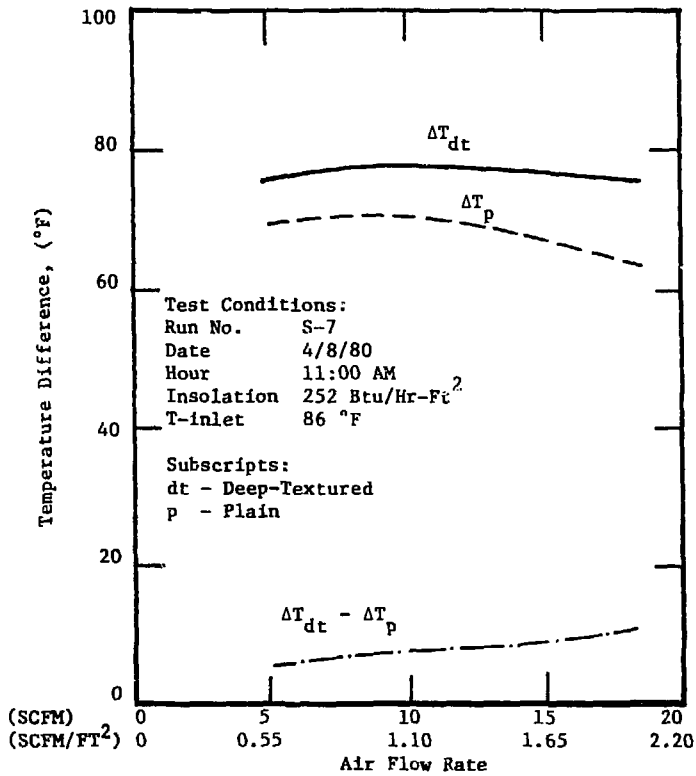


Figure 2. Comparison of Temperature Difference for Deep-Textured and Plain Plate collectors.

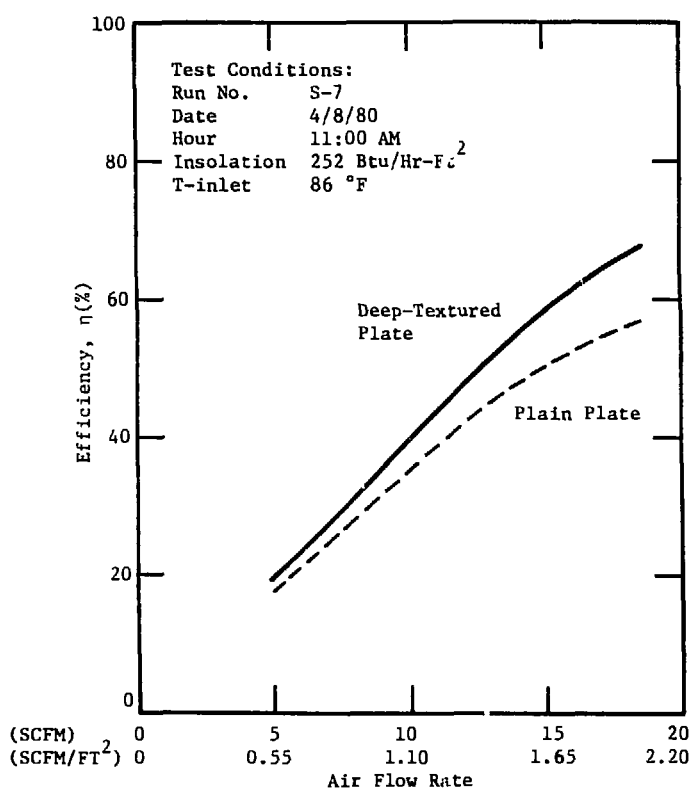


Figure 3. Efficiency of Deep-Textured and Plain Plate collector as Function of Air Flow Rate.

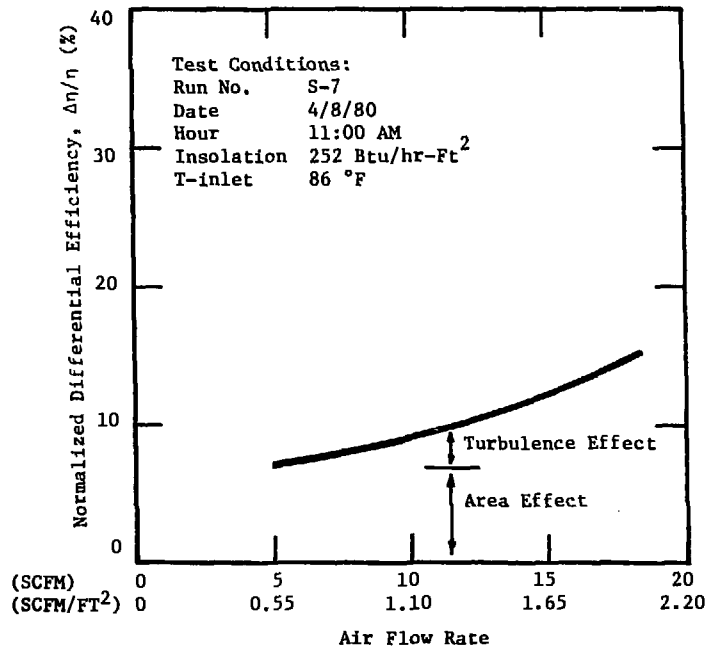


Figure 4. Normalized Differential Efficiency versus Air Flow Rate.

TUBULAR SOLAR COLLECTOR ANALYSIS AND COMPARISON WITH FLAT PLATE COLLECTORS IN SDHW APPLICATIONS

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EXTENDED ABSTRACT

INTRODUCTION

An in-depth theoretical and experimental study of a solar domestic hot water system located in Rochester, New York, has been performed. The configuration of the system is a two-tank, indirect, internal heat exchanger scheme using a 50/50 water and propylene glycol antifreeze solution. Commercially available tubular collectors are utilized in the system. The procedure used in the analysis was as follows. First, an analytical model was developed for the tubular collectors. Experimental verification of the mathematical model was then performed. The results were then used to calibrate the TRNSYS computer simulation program configured to simulate the operating system. Simulations were then done for both tubular and flat plate systems, utilizing meteorological data typical of the region. Finally, a cost/benefit analysis of each system was performed.

TUBULAR COLLECTOR ANALYSIS

The analysis of the tubular collectors parallels that of the HWB approach for flat plate collectors. Due to the geometry of the collectors, however, variations in the HWB approach are required. The collectors are manufactured by the KTA Corporation and are constructed utilizing a copper conduit absorber enclosed by two glass envelopes. The outer envelope is silvered on the lower half for back reflection of insolation onto the absorber. The circular geometry can be accounted for by rewriting the collector efficiency equation in the following form:

$$\eta_{\text{tub}} = F_R(\tau\alpha)_e \Gamma - F_R U_L \frac{\pi d}{D} \frac{T_{\text{inc}} - T_a}{I} \quad (1)$$

where: F_R is the collector heat removal factor which relates the useful heat gain to the useful heat gain if the whole collector is at the fluid inlet temperature; $(\tau\alpha)_e$ is the transmittance, absorptance product of the

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cover system; Γ is defined as the radiation enhancement factor; U_L is the overall heat transfer coefficient between the absorber tube and the surroundings; d is the absorber tube diameter; D is the silvered outer cover tube diameter; T_{inc} is the collector inlet temperature; T_a is the ambient temperature; and I is the insulation on the tilt plane of the collector.

The enhancement factor Γ accounts for the fact that of the total radiation falling on the collector aperture area, only a portion is directly intercepted or back reflected to the absorber tube. In order to simplify its evaluation, the enhancement factor can be rewritten [1],

$$\Gamma = \Gamma_b \frac{I_b}{I} + \Gamma_d \frac{I_d}{I} \quad (2)$$

where Γ_b and Γ_d are the beam and diffuse enhancement factors respectively and I_b and I_d are the beam and diffuse components of the total insolation I . Factors influencing the value of Γ_b are: (i) the degree to which the absorber tube is shaded by adjacent tubes; (ii) reflectance of the silver backing of the outer cover tube over the solar spectrum; and (iii) the fraction of incident radiation on the aperture cross section that is ultimately reflected to the absorber tube by means of the silver backing.

The $(\tau\alpha)_e$ of the cover system was analytically evaluated as was the overall heat transfer coefficient U_L for a variety of climatological conditions.

EXPERIMENTAL VERIFICATION OF COLLECTOR MODEL

Several tests were performed utilizing the system described previously for the purpose of evaluating the parameters of Equation 1. Results of the experiments as well as the analytic results are given below.

<u>Parameter</u>	<u>Experimental Result</u>	<u>Analytical Result</u>	<u>Comments</u>
U_L	5.9 W/m ² °C	4.7 W/m ² °C	Winter
	5.7 W/m ² °C	4.5 W/m ² °C	Summer
$(\tau\alpha)_e$	.90	.80	Constant

TRNSYS SIMULATION

The system was modeled using the TRNSYS simulation program for collector parameters given below.

Parameter	Tubular	Flat Plate (Selective)	Flat Plate (Non-selective)
($\tau\alpha$)	.90	.73	.76
U_L	5.8 W/m ² °C	4.4 W/m ² °C	5.7 W/m ² °C
Mass Flow Rate	246 kg/hr	246 kg/hr	246 kg/hr
Fluid Specific Heat	3.4 kJ/kg°K	3.4 kJ/kg°K	3.4 kJ/kg°K
Area	5.9 m ²	6.7 m ²	6.7 m ²
F_R	.95	.90	.88

The DHW profile choosen was developed by a Rand Corporation survey [2] and applies to a 'typical' residence. It is a normalized daily mass flow rate profile which when multiplied by the daily total consumption gives instantaneous values. For this study, 300 kg/day or 20 gallons per day per person for a family of four was used.

Actual insolation data from tilted and horizontal pyranometers on location were used in the simulation. Rather than performing an extensive simulation which would require large quantities of data to be inputed to the program, an alternate, simplified procedure was used. Later work in a companion study revealed results that were approximately 6 percent greater than those obtained using the simplified approach.

The simulations were performed for each collector configuration using typical insolation data for both January and June. Ambient temperature data were obtained from the Rochester National Weather Service Office.

RESULTS

From the simulations performed utilizing the previously outlined method, the following average yearly performances were observed:

System	% Annual DHW Load Supplied by Solar
Tubular	25
Flat Plate - Selective Absorber Plate	36
Flat Plate - Regular Absorber Plate	34

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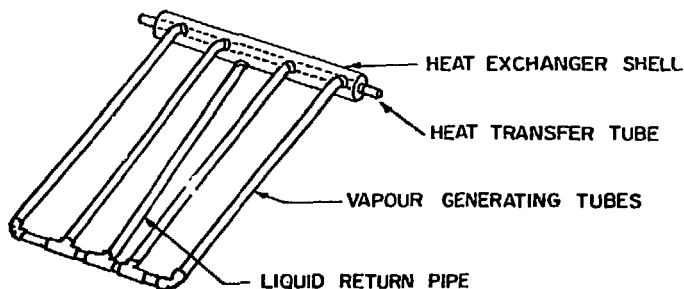
THE SOLARSIPHON FLAT PLATE COLLECTOR

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EXTENDED ABSTRACT

A flat plate collector incorporating a two-phase thermosiphon as the means of transferring energy collected on a black collecting surface to water passing through a horizontal heat transfer tube located at the top of the collector is described.

A sketch of an apparatus which accomplishes this kind of heat transfer is shown below.

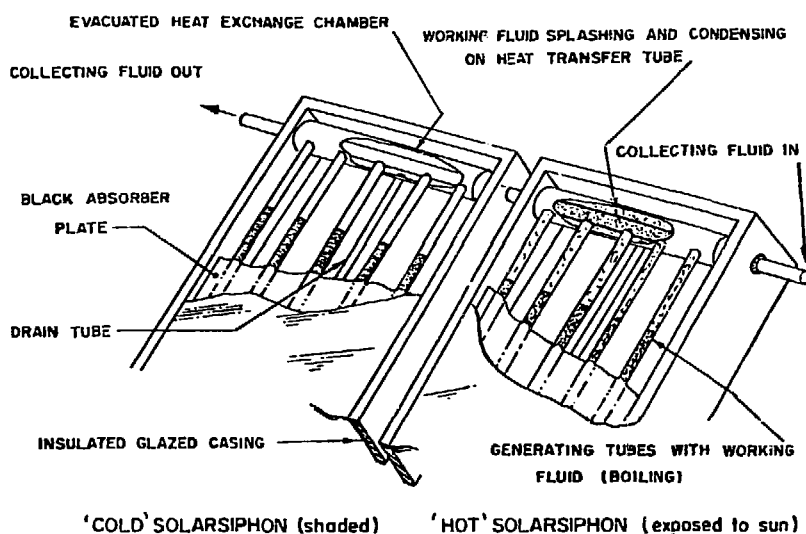


Vapor generated in the vapor generating pipes causes a mixture of vapor and liquid to rise up the pipes and into a top chamber where it splashes against the heat transfer tube. The space containing the working fluid is a sealed space which is evacuated before the fluid is introduced. Enough fluid is introduced to partially fill the volume with liquid and the rest of the volume with vapor. The boiling action in the vapor generating pipes is caused by thermal energy supplied from a solar energy absorbing plate attached to the pipes. The heat transfer at the heat transfer tube occurs because of direct liquid splashing combined with vapor condensation. To visualize the boiling process a glass apparatus has been built and motion pictures obtained for various operating con-

ditions. A number of copper test rigs have also been built and tested to obtain heat transfer information. These laboratory rigs make use of electric heaters wound around the vapor generating pipes as the source of energy to the boiling fluid because of the ease of control and measurement.

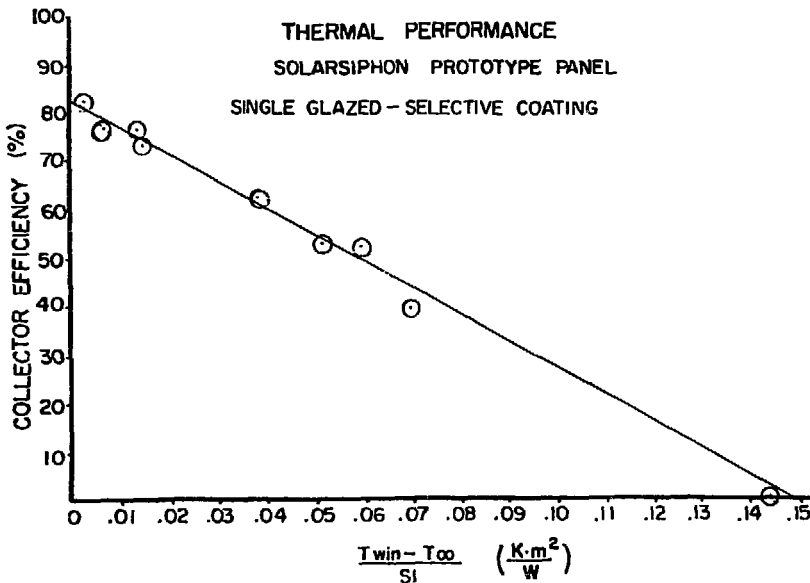
The results obtained with these rigs show that good heat transfer can be achieved and that the temperature differences required between collecting surfaces and water passing through the heat transfer tube are comparable to those obtained with conventional solar collectors. The working fluid used in the sealed space of the two-phase thermosiphon determines how well the energy transfer takes place. Suitable fluids include some of the freons, alcohols, and water. Water gives the best performance but unfortunately damages the thermosiphon if it becomes frozen. The addition of one of the glycols prevents freeze damage without an undue effect on the thermal performance of the thermosiphon.

The incorporation of a two-phase thermosiphon with splash heat exchanger into a solar collector has been dubbed "The Solarsiphon" and is illustrated below.



Solar collectors incorporating two-phase thermosiphons with splash heat exchangers provide important operating characteristics and technical advantages. Amongst these are: the diode operating nature of the device which provides a low resistance heat transfer path for energy collected on an absorber surface and being transferred into a collecting fluid passing through the heat transfer tube and which substantially prevents energy transfer in the opposite direction when the absorber grows cold and the collecting fluid remains warm; the horizontal position of the heat transfer tube which simplifies piping arrangements; and the sealed environment for the working fluid by which fouling of the collector pipes is avoided and the stability of the working fluid is protected.

A number of solarsiphon collectors have been built and tested during the development program aimed at producing a commercially available collector. The performance of the final prototype in this program is shown in the following figure.



THERMAL PERFORMANCE OF FLAT PLATE SOLAR
COLLECTORS USING AN AIR GAP AND/OR RADIATION
SHIELDS AS REAR INSULATION

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EXTENDED ABSTRACT

INTRODUCTION

Flat plate solar collectors have the potential for providing thermal energy for low and moderate temperature applications. The classical flat plate solar collector comprises basically a radiation absorbing black flat plate under a transparent cover, with the underside of the absorbing plate being insulated to reduce rear heat losses. The heat absorbed by the plate is transferred to a cooling fluid such as water or air passing through appropriate passages attached to the absorber plate. The useful energy extracted from the absorber plate may be increased by reducing the heat losses from the plate to the surroundings. Various means and methods have been devised to minimise the 'top' or 'front' heat losses[1]. The 'bottom', 'back' or 'rear' heat losses are normally taken care of by providing a sufficient thickness of insulating material thus reducing these losses to one predominantly of conduction. When loose fill material such as mineral wool or coconut fibre is used as insulation, there is a tendency, under the humid conditions normally prevalent in the tropics, for moisture to be absorbed and subsequently released at the higher operating temperatures of the collector. This moisture then condenses on the cover glazing causing fogging and a loss of transmissivity.

In this paper the role of the rear insulating material is examined and the conditions under which this material may be dispensed with and the air between the absorber plate and the rear casing may itself be able to provide the insulation, are studied.

NATURAL CONVECTION BETWEEN ABSORBER PLATE AND REAR CASING

When the insulating material at the rear of the absorber plate is dispensed with the losses through the rear take place by natural

convection and radiation between the rear of the absorber plate and the inside of the rear casing. Essentially this reduces to a problem in downward convective heat transfer between parallel plates. The phenomena of free convective heat transfer between parallel plates has been extensively studied for heat flow upwards and the relationships governing this heat transfer for any inclination of the plates may be considered to be reasonably well established[2]. However, the problem of free convective heat transfer between parallel plates for heat flow downwards has not been subjected to such intensive examination.

Normally flat plate collectors are tilted from the horizontal at an angle appropriate for optimum irradiation. In Trinidad (latitude 10°) the optimum year round performance of the collector, based on insolation data, occurs at a collector tilt of 10° South. For free convective downward heat transfer between parallel plates, using Tabor's results[3] and that of Wilkes and Peterson[4] the following relationships may be considered to be valid for an inclination of 10° :

$$\begin{aligned} Nu &= 0.3145 (Gr)^{0.122} \text{ for } 3 \times 10^4 < Gr < 1 \times 10^5 \\ &= 0.1374 (Gr)^{0.194} \text{ for } 1 \times 10^5 < Gr < 5 \times 10^5 \\ &= 0.0916 (Gr)^{0.225} \text{ for } 5 \times 10^5 < Gr < 5 \times 10^6 \end{aligned}$$

RESULTS AND DISCUSSION

Using the above relationships, the total useful energy gain of a flat plate solar collector was computed for Trinidad for the month of March, when the space between the collector plate and rear casing is

- (a) filled with insulating material of thermal conductivity $0.0465 \text{ W m}^{-1} \text{ C}^{-1}$
- (b) filled with insulating material of thermal conductivity $0.0346 \text{ W m}^{-1} \text{ C}^{-1}$
- (c) an air gap
- (d) an air gap fitted with a radiation shield.

It is shown that the thermal loss through an air gap at the rear amounts at most to some 3% of the total daily useful energy gain over the loss when the space is filled with an insulating material

of thermal conductivity $0.0465 \text{ W m}^{-1} \text{ C}^{-1}$. If now a thin aluminium foil is interposed as a radiation shield in the air gap then the rear heat loss is about the same as that when the space is filled with insulating material of thermal conductivity $0.0346 \text{ W m}^{-1} \text{ C}^{-1}$. Considering the fact that rear insulation normally contributes to about 10% of the cost of the collector and that the cost of a thin radiation shield is about 10% of the cost of the insulation, the cost effectiveness of using an air gap and/or radiation shield as rear insulation, particularly at low latitudes, becomes quite evident.

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A FLAT-PLATE SOLAR COLLECTOR WITH SPIRAL TUBING

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EXTENDED ABSTRACT

In this work, a flat-plate collector having a circular absorbing plate with a spiral tube for fluid passage is investigated. An analytical expression is obtained for the collector outlet temperature. The whole system is considered as lumped at a mean temperature and daily variation of the mean fluid temperature is determined numerically. Thermosyphon flow is analysed using a system temperature distribution diagram and a polynomial expression is obtained for the thermosyphonic flow rate which is then solved on a digital computer using the knowledge of mean fluid temperature. Experiments are performed with a spiral-tube collector model and fairly good correlations are obtained for the mean temperature. Flow rate could not be measured in the experiments.

Some problems related to the development of thermosyphon flow were observed in the experiments. The system had long transients before the normal flow could develop. However, this problem was partly due to the steel plate being massive and therefore inefficient. Computed thermosyphonic flow rates were around 3 g/s for a clear summer day, experimental daily efficiencies being 35-40 percent.

Spiral-tube collector has several advantages over the conventional sheet-and-tube type with riser-header arrangement. Temperature increase from collector inlet to outlet is higher in a spiral-tube collector. This is an advantage where high temperature is required. Secondly, average tube-to-fluid heat transfer coefficient is greater owing to the curvedness of the tube. Thirdly, lower heat losses are possible because fluid in the spiral tube flows toward the center of the plate and therefore the hottest spot is in the center of the plate (1). Fourthly, in conventional collectors flow uniformity and therefore the design of headers are important in obtaining good collector performance (2). In spiral-tube collectors flow uniformity is not a problem since no headers are used. Finally, spiral-tube collectors are easier to manufacture and therefore should be less costly.

It is concluded in the study that it is worth to investigate further the characteristics of spiral-tube collector and to experiment with a spiral-tube and a conventional type collector under identical conditions and to compare their performances.

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THE HYBRID SOLAR COLLECTOR

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EXTENDED ABSTRACT

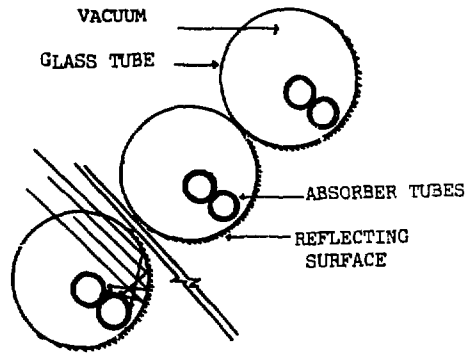
Pakistan receives a substantial amount of solar radiation throughout the year, of which the direct component is significant. However, during mid summer and midwinter there are often periods of prolonged cloud cover. Because dust suspensions are also not uncommon, it is relevant to design a solar collector that will continue to operate throughout these changes in insolation, yet will capitalize on the direct component of incoming energy.

Flat plate collectors are limited in the maximum temperatures they achieve yet their ability to perform even in diffuse radiation conditions gives them a large range of operation. Conversely, optical concentrating techniques can attain higher temperatures, but are severely handicapped by their inability to function when light is of a scattered nature. A hybrid solar collector was built utilizing the potentials of nontracking optical concentration in conjunction with flat plate absorption and preliminary performance tests indicate the device can be developed into a useful energy converter for regions which receive high dosage of direct insolation. Solar tubes working on the Philips Mk I concept were constructed and installed above a conventional flat plate collector, See fig 1, to achieve a staged engineering concept. Test data is presented in the paper in the form of tables and graphs. No comparative studies were undertaken, because of limitations in construction and testing facilities. However, pertinent information indicating the capability of the device is stated.

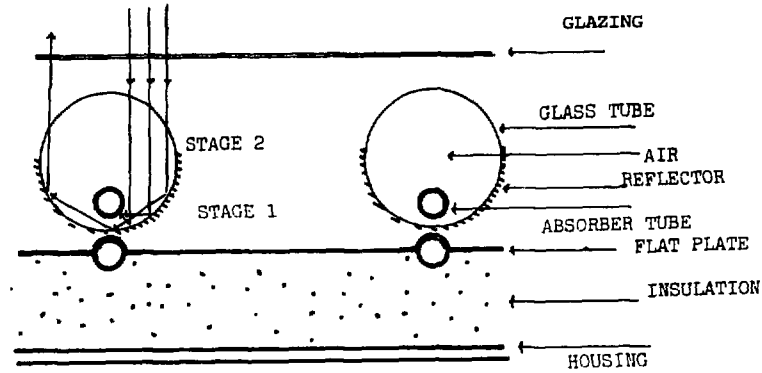
CONCLUSIONS

The Hybrid solar collector has some outstanding characteristics that justify further development of the device

- a) Beam radiation is converted to heat both in the shaded flat plate stage and the solar tube array. Diffuse radiation is absorbed throughout the flat plate area.
- b) The solar tubes are a higher temperature zone that simultaneously provides a double glazing insulating effect.
- c) No moving parts.
- d) Potentially suited for energizing absorption cooling, rankine pumping and thermal power installations.
- e) The concept emphasizes the importance of utilizing direct solar radiation in areas like Pakistan where it is available in abundance and where it is becoming necessary to develop effective solar technology that is indigenous and economically viable.



PHILIPS MkI SOLAR TUBE



THE HYBRID SOLAR COLLECTOR

FIGURE 1.

Some Studies of a Non-Imaging Linear Fresnel Lens.

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and

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A_B_S_T_R_A_C_T

Recently, Collares Pereira (1,2) has undertaken research on utilizing the CPC design principle for developing two-stage solar concentrators in the form of lens mirror combinations. Whereas the formation of an image of the Sun in the focal plane of the concentrator is the basis of all imaging concentrators, the CPC design principle is essentially a non-imaging concept. The solar radiation incident on the concentrator aperture within a given acceptance angle is merely concentrated on the target/receiver and the concentration achieved is maximised by using the CPC design principles.

In this paper, an analysis of the design and performance of a non-imaging Fresnel lens of the type proposed by Collares-Pereira (2) is presented. According to this proposal, a lens made up of two segments arranged in the form of an inverted vee is considered to be a simpler version of the curved base Fresnel Lens (3,4,5).

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Design studies in the case of such a non-imaging Fresnel lens are undertaken and a simple analytical model for determining the concentration is presented. Taking into account the solar spectral distribution and the finite angular subtense of the sun and also the transmission properties of acrylic, expressions for beam spread and transmittance of each serration in different wavelengths are derived in order to calculate the focal plane concentration and total lens transmittance. The dependence of concentration on the serration width, slope angle and focal length have been studied and presented graphically.

Preliminary investigations reveal that the combination of the Fresnel and CPC design principles provides an advantageous alternative to concentrator design. The advantages gained are in terms of concentration, transmittance, relaxed tracking requirements and ease of fabrication. Studies on prediction of the long term performance of this system are in progress. The approach followed for this purpose is again that of Collares Pereira and Rabl (6) which is essentially a generalized and simplified version of the well-known Liu and Jordan model (7) and needs as meteorological input only the long term average daily total hemi-spherical irradiation on a horizontal surface and the long term average daily ambient temperature. Some results for a non-imaging linear Fresnel lens solar concentrator will be presented graphically and discussed.

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AN ANALYTICAL MODEL AND PERFORMANCE DATA FOR A CYLINDRICAL PARABOLIC COLLECTOR

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EXTENDED ABSTRACT

INTRODUCTION

Concentrating solar collectors provide higher fluid temperatures than flat-plate collectors, an important advantage in many applications. The parabolic cylinder is one of the most popular types of concentrating collectors because of its relatively simple construction and tracking configuration. A mathematical model was developed for one such collector - the "SOL-R-BEAM", manufactured by Beam Engineering - in order to predict thermal efficiency as a function of solar insolation and weather parameters. This prediction was then compared to experimental data.

THEORY

It can be shown that the incidence angle, θ , of direct solar radiation as it strikes the aperture of an east-west tracking, south-facing collector whose axis is tilted at an angle β with the horizontal, is

$$\cos \theta = \left[(\sin (\phi - \beta) \sin \delta + \cos (\phi - \beta) \cos \delta \cos w)^2 + \cos^2 \delta \sin^2 w \right]^{\frac{1}{2}} \quad (1)$$

where ϕ = local latitude
 δ = solar declination
 w = solar hour angle [1] .

The collector thermal efficiency is then

$$\eta = \frac{q_u}{A_a I_D}$$

where q_u = useful heat extraction from collector
 A_a = collector aperture area
 $I_D = I_{DN} \cos \theta$ (2)

and I_{DN} is the amount of insolation measured using a normal incidence pyrheliometer. This value of thermal efficiency is determined from

experimental values of I_D and experimentally measured or theoretically predicted values of q_u .

The useful heat output of a parabolic cylinder collector may be given theoretically by

$$q_u = A_a F_R \left[I_D \rho \gamma \tau \alpha - \frac{A_r U_L}{A_a} (\tau_{f,i} - \tau_a) \right] \quad (3)$$

where F_R = collector heat removal factor
 ρ = collector cover reflectance
 γ = collector intercept factor
 τ = collector cover transmissivity
 α = collector receiver absorptivity
 A_r = receiver area
 U_L = heat loss coefficient
 $\tau_{f,i}$ = inlet fluid temperature
 τ_a = ambient air temperature 2 .

Thus the efficiency is

$$\eta = F_R \left[\rho \gamma \tau \alpha - \frac{A_r U_L}{A_a I_D} (\tau_{f,i} - \tau_a) \right] . \quad (4)$$

In order to simplify the mathematical model it was assumed that η varied only with $(\tau_{f,i} - \tau_a)/I_D$. The efficiency curve is therefore a straight line with slope $-F_R A_r U_L / A_a$ and γ - intercept $F_R \rho \gamma \tau \alpha$.

RESULTS

The thermal efficiency of the SOL-R-BEAM based on the theoretical heat balance was found to be

$$\eta = 65.0 - 1.2 \frac{\Delta \tau}{I_D} \quad (5)$$

while the efficiency based on experimental results alone was

$$\eta = 57.0 - 2.3 \frac{\Delta \tau}{I_D} . \quad (6)$$

The discrepancy between the two can be attributable both to oversimplification of the mathematical model and to faults in the experimental procedure. Suggestions were made for improving both.

- 84 -

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STEADY STATE AND TRANSIENT MODEL
OF A LINEAR SOLAR CONCENTRATOR
WITH CYLINDRICAL ABSORBER

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EXTENDED ABSTRACT:

INTRODUCTION

A linear parabolic collector with integrated absorber pipe assembly is one of the main elements of a solar energy collection system that produces electricity or process heat. This kind of a system must geometrically and thermally be optimized so that a reasonable operating efficiency can be reached.

A linear parabolic collector having an absorber, encircled with a cylindrical cavity, has been studied and the geometrical parameters of the system have been optimized before the collector was built and put into operation. The thermal parameters are studied very briefly using a theoretical model that is built for the system.

GEOMETRICAL PARAMETERS

The optimization procedure of the geometrical parameters has been carried out so that a reasonable concentration is obtained along the focal line. The collector having dimensions of 200x95 sq.cm. and having a focal length of 60 cm. is built with the view of the optimization procedure.

The collector is oriented EW horizontal in the NS tracking mode and the longitudinal deviations of the focal line is examined.

The energy distribution around the focal line of the collector is measured using a laser together with a wattmeter.

THERMAL AND OPTICAL PARAMETERS

The effects of the thermal and optical parameters on the performance of the system is studied by the use of a theoretical model that is built for the collector absorber system. The parameters considered in the analysis are:

1. the thermal capacities of the absorber pipe (C_2) and the cylindrical envelope that surrounds the pipe (C_1),
2. the radiative resistance between the absorber and the envelope (R_1) and between the envelope and the ambient (R_L),
3. the energies absorber by the envelope (Q_1) and by the absorber (Q_2).

To see the effect of these parameters each one is changed from a minimum to a maximum keeping the other parameters at their average values.

CONCLUSION

The optimization of the system parameters using the steady state and transient model seems to be a very powerful technique since the capacitive and resistive terms include these parameters. The geometrical, thermal and optical parameters are all contained in the model and by iterative technique different aspects of the system can be optimized.

A brief analysis of the results can be tabulated as follows:

	Increased by	Deviation of the steady state values	Change of time of saturation (sec)	Comments
C_1	42	+2	-2000	Recommended
C_2	1.4	-1	+3000	Not recommended
R_1	10	+2	-600	Recommended
R_L	125	+7	-3900	Highly recommended
Q_1	18	-22	-3000	Must definitely be avoided
Q_2	4	+7	-600	Highly recommended

ACKNOWLEDGEMENT

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STATIC LOADING AND WIND EFFECTS ON RRSRR SOLAR TRACKING SYSTEM

by

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ABSTRACT

The purpose of this work is to investigate the effects of wind forces on the static loading of an RRSRR solar tracking system. It is the second of a series of papers on the design of an RRSRR solar system.

The RRSRR system, which employs double axes for the displacement of its solar panel, enables in concept, a small mechanism to drive large panels or collectors. The actual size of the mechanism is determined, however, on the basis of strength considerations (mainly due to wind forces). Thus, to allow the selection of a suitable size mechanism, the work presents static equilibrium equations in a convenient matrix form. An example problem is given, and the effects of wind loading and design parameters on the performance of the mechanism are shown. Design curves are also plotted, and conclusions are drawn.

STATISTICAL DETERMINATION OF DIFFUSE RADIATION IN EUROPE AND TURKEY

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EXTENDED ABSTRACT

INTRODUCTION

The aim of the study is to develop a statistical method for the determination of diffuse radiation in Europe and Turkey. 37 stations measuring both diffuse and total radiation have been analyzed and 19 well selected stations were used for the European correlation and 14 for Turkey. The solar constant is assumed to be 1353 W/m². Diffuse and total radiation data received from various stations have been accepted as such, and some stations which yielded unusual results were excluded from the study. This investigation has transformed solar data into linear correlations. A computerized program based on the least squares method has been used to produce the linear correlations from which the diffuse component can be calculated if total radiation is known.

BACKGROUND

Liu and Jordan [1] originally studied 4 stations. Their findings have been formulated by Klein [2] thus:

$$\bar{H}_d/\bar{H} = 1.39 - 4.03 \bar{K}_T + 5.53 \bar{K}_T^2 - 3.11 \bar{K}_T^3 \quad (1)$$

This curve is traced on Fig. 1. Later, Page [3] studied 1 US, 2 European and 7 African stations and proposed the following correlation:

$$\bar{H}_d/\bar{H} = 1.00 - 1.13 \bar{K}_T \quad (2)$$

Here $\bar{H}_d$ is daily diffuse radiation, $\bar{H}$ is daily total radiation and $\bar{K}_T = \bar{H}/\bar{H}_o$ where $\bar{H}_o$ is extraterrestrial daily insolation, all measured on a horizontal surface and averaged over the month.

EFFECT OF LATITUDE

Radiation data has been analyzed to determine the effect of latitude on diffuse radiation. In some instances it seemed that diffuse radiation "escalates" with latitude, that is, northern cities assume higher positions on Fig. 1. However in many cases the opposite was found to be true. Consequently, it can be stated that dif-

diffuse radiation and latitude are not necessarily interrelated.

ANALYSIS OF RADIATION DATA

Radiation data has been acquired through technical literature and private communication with the meteorological departments of numerous countries. The data was sorted out and the results of a number of cities are shown below on Fig. 1. The

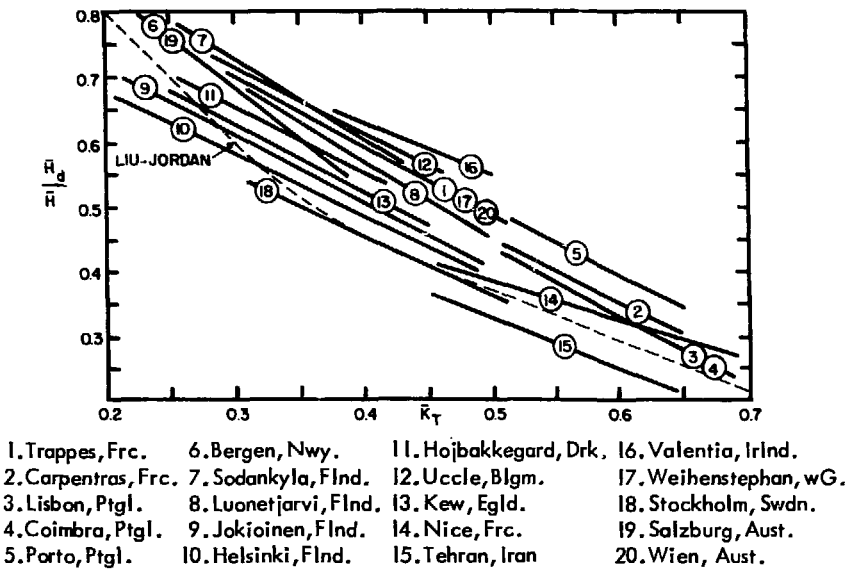


Fig. 1 Radiation data

first observation is the slope of the plotted lines—they seem to be almost consistent. The second observation is the wide distribution of data input points all over the graph. Consequently it is felt that the behavior of diffuse radiation is varied and the development of a single correlation commanding world-wide acceptance is difficult. Such an analysis should be confined to restricted regions and diffuse radiation should be determined by statistical methods only for lack of something better, that is, actual diffuse radiation data.

CORRELATIONS FOR EUROPE AND TURKEY

A least squares linear fit for 19 stations in Europe yields the following equation:

$$\bar{R}_d/\bar{H} = 0.978 - 1.066 \bar{K}_T \quad (3)$$

Turkey's correlation covers 1 Asian and 13 European stations and is expressed thus:

$$\bar{H}_d/\bar{H} = 1.065 - 1.246 \bar{K}_T \quad (4)$$

The results are shown on Fig. 2. Obviously there is very close agreement with

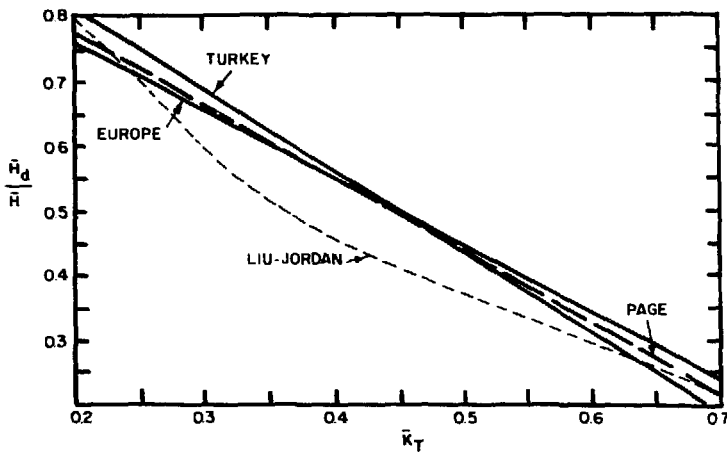


Fig. 2

Page and deviation from Liu and Jordan is within tolerable limits. Total radiation on tilted surfaces has been calculated, comparing Liu and Jordan's curve with the present study, and average deviation was found to be 6%.

CONCLUSIONS

1. Statistical determination of diffuse radiation should not be attempted on a world wide scale and should be confined to restricted regions with similar climates.
2. Direct measurement of diffuse radiation is the only reliable method of determining it.

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COMPRESSED AIR ENERGY STORAGE--ECONOMIC
PEAKING AND RESERVE CAPACITY FOR
SOYLAND POWER COOPERATIVE

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The Soyland Power Cooperative is planning a pioneering addition of a compressed air energy storage (CAES) unit to its system in Southern Illinois. This CAES unit represents an innovative application of machinery proved in other arrangements. A similar unit installed at Huntorf, West Germany, has demonstrated the technical soundness of the system during its two years of operation.

The system planned is a water compensated, hard rock cavern CAES. Air compression and energy production are accomplished with conventional air compression/gas turbine machinery by placing clutches between these components and a motor/generator. The plant schematic is presented on Figure 1. During off-peak hours, the motor/generator, driven by electricity from the grid, acts as a motor to drive the compressor, which pumps air into an underground storage reservoir, displacing an equal volume of water to a ground level reservoir. During periods of peak demand, the air is removed from storage, heated in the combustion chamber, and expanded in the turbine driving the motor/generator to deliver electricity to the grid. No power from the gas turbine is used to run the compressor; consequently, higher net generating efficiency is achieved. This paper provides details of the planned facility, including its machinery, and operating characteristics. Figure 2 shows an artist's rendering of the CAES plant.

In comparison to other available systems used to satisfy peak load electrical demands, the CAES system could result in greater reduction in the nation's use of oil. A CAES unit, when integrated into the electrical grid, will effect a net gain in total system efficiency by allowing the larger, more efficient fossil and nuclear units to run at their peak efficiencies for longer periods of time. In addition, CAES can be utilized in the future to provide the storage system

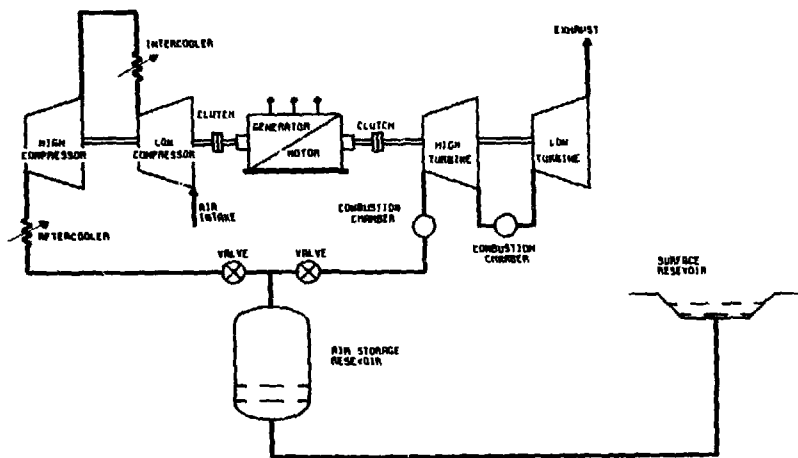


Fig. 1 - Water Compensated Hard Rock Cavern
CAES Plant Schematic

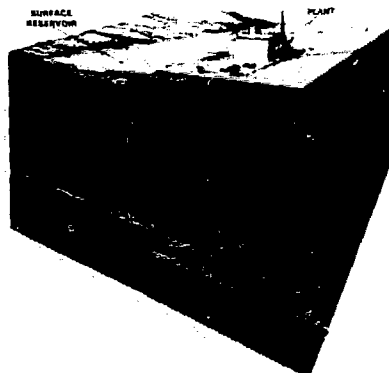


Fig. 2 - CAES Plant -- Artist's Rendering

required for the naturally occurring random energy sources, such as solar or wind. These and other considerations of this facility related to the U.S. programs sponsored by the Department of Energy (DOE) Divisions of Energy Storage Systems (STOR) and Electric Energy Systems (EES) are discussed in the paper.

Study of methods to meet the Soyland Power Cooperative's need for peaking capacity indicates that under a variety of economic assumptions, the option providing the greatest benefit to Soyland and its customers appears to be the construction of a CAES. This study took into account construction and operating costs, including charges for purchasing power from other utilities, as well as considerations of system benefits due to the spinning reserve nature of a CAES. This paper provides data developed in the study and the reasoning leading to the conclusions.

EQUIVALENT CIRCUIT PARAMETRIC MODEL REQUIREMENTS OF THE
REDOX FLOW CELL FOR BULK ENERGY STORAGE

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The redox flow cell as energy generator and storage device operates on the principle of oxidation-reduction in which the redox couple $\text{Fe}^{+3}/\text{Fe}^{+2}$: $\text{Ti}^{+3}/\text{Ti}^{+4}$ remain soluble in their electrolyte in either the oxidized or reduced state.

Previous research work carried out by this author identified basic gyromagnetic characteristics as well as quantum parametric identification for the ferromagnetic fluid flow in the catholyte continuum of the redox flow cell, which are needed as reliable information to design the proper mechanism for neutralizing the internal circulating currents and hence extending the redox flow cell performance at all levels of loading and output voltage. Those previous results indicated clearly that at ferro-resonance, the catholyte gyromagnetic resistance as well as the magnetic susceptibility become very large at which the induced internal circulating currents almost disappear. At ferro-resonance the loading specific magnetomotive force is established as well as peak values for the gyromagnetic energy, resistance and magnetic susceptibility.

Also research investigation conducted by Bogardus, Krueger and Thompson indicated clearly the response of water-based ferrofluid to the application of a pulsed magnetic field, where magnetization and subsequent relaxation are attributed to rotation of magnetite particles and moments orientation. The same work also identified a slow as well as fast components of demagnetization and a rotational time constant of the order of 1 msec. The expectation of 1 msec time constant value for particles rotation as well as moment orientation put a forced constant on the relationship of layer surfactant thickness with respect to particles diameter.

This author supplemented his previous work on the magnetization of ion dipoles of ferrofluid with that of particles alignment and moments orientation by establishing mathematical loci in the plane of surfactant thickness with respect to particle diameters, solution for the state of particles magnetization due to a sustained DC magnetic field and then an approximate solution for magnetite distribution function.

The magnetites distribution function is derived as three distance functions, each confined to a limited spatial limitation, as extracted from the well defined Bell function from its 2nd derivative.

Listed below

1. Locus of τ_r in the $h V_s D_1$ plane

$$z = |z| e^{j(\phi+\alpha)}$$

$$z_{\min} = z_o e^{+j\alpha} \quad (1)$$

z is the radial vector

2. Locus of τ_n is constrained by a change in negative slope of 0.15 for an increase in spheroid aspect ratio of 10 per-cent for two particles and of 0.5 for increase of number of particles from 2 to 4.

3. Solution of the state of magnetization $M(t)$:

$$M(t) = \frac{\gamma H_o R}{2kT} U_1(t) - \frac{\gamma H_o R \tau}{2kT} e^{-\frac{t}{\tau}} \quad (2)$$

$$R = \frac{n M_s^2 V^2}{\gamma} \int_{-1}^{+1} (1-x^2) f(x) dx \quad (3)$$

and

$$\tau = \gamma / 2kT \quad (4)$$

4. Solution of particles distribution function $f(x)$:

$$f(x) = f_1(x) + f_2(x) + f_3(x)$$

$$f_1(x) = 9.7 x^5 \text{ for } 0 < x < \pm \frac{1}{2}$$

$$f_2(x) = -9611 x^2 + \frac{12928}{3} x^3 \text{ for } \frac{1}{2} \pm < x < \pm \frac{3}{4} \quad (5)$$

$$f_3(x) = -122 x^2 + 92 x^3 \text{ for } \frac{3}{4} \pm < x < \pm 1$$

where

n = concentration
 M_s = saturation level for magnetization
 V = particle magnetic volume
 γ = mobility
 H_o = strength of magnetic field step function
 k, t = Boltzman contant and absolute temp.

Derivation of the redox flow cell equivalent circuits sets the direct mechanism for total elimination of the induced circulating current at any load and voltage level, while the mathematical model define the required spectrum for the steady state and transient performance as well as stability limitations. The importance of the redox flow cell could be realized as a reliable electric generator and also as a device for bulk energy storage, where it occupies a physical size of no more than three per-cent of a comparable hydro-electric plant of the same MW capacity.

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ROOFTOP COLLECTOR GROUND RESERVOIR
PUMPLESS CONTROLLED CIRCULATION SYSTEM

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EXTENDED ABSTRACT

One of the great advantages of the thermal siphon circulation system is that, although it is passive, it is self-regulating. Unfortunately this system requires a rooftop reservoir. The installation of a large reservoir (>1 ton for home heating) is impractical in homes with wood construction, which is prevalent in California due to earthquake safety requirements. The alternative is to utilize a thermostat-controlled electrical pump, an approach that consumes high-grade energy and is expensive. This paper discusses the use of nonlinear resonant circuit techniques that employ a special pressure release valve and a unidirectional valve. These valves excite the hydraulic circuit in an under-damped mode to provide circulation driven by the temperature gradient between the collector and the reservoir. The system is self-regulating and passive, the water being the only moving part.

SYSTEM SIMULATION AND VERIFICATION OF A STORAGE-TYPE
HEAT EXCHANGER USED IN A SOLAR DOMESTIC HOT WATER SYSTEM

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EXTENDED ABSTRACT

A storage-type heat exchanger (bare copper tubing or finned copper tubing placed inside the water storage tank) has been used widely in solar domestic hot water systems. This type of heat exchanger has been frequently adopted into solar system design, especially in residential and small-scale commercial applications.

However, to analyze the heat transfer phenomenon of a storage-type heat exchanger in a solar domestic hot water system is not an easy task. The transient effect of the solar radiation as well as the variation of the demand for domestic hot water load make the problem even more complicated. Existing tables or charts for determining the effectiveness of a conventional heat exchanger are not applicable for this system. Although there are some rule of thumb methods being used to estimate the total required heat transfer surface area (i.e., estimate the length and diameter of the tube), unfortunately there are no sufficient systematic experimental results to verify these methods.

The objectives of this study are twofold: first is to develop a mathematical model which can be used to simulate the heat transfer phenomenon of a storage-type heat exchanger under some reasonable assumptions and second is to verify this mathematical model by comparing the analytic calculations with experimental results.

Figure 1 shows the schematic of the mathematical model and the key parameters used. A dynamic computer program using Continuous System Modeling Program III (CSMP III) was developed to solve the mathematic governing equations. The computer program calculated the water temperature in the tank and printed out the exiting water temperature of the heat exchanger respective to the hot water load demands. The measured data on the collector inlet and outlet water temperature and the profile of hot water load demand of the system were used as part of the input data to the computer program.

The output of the computer program was verified with a drain-down domestic water system installed in Socorro High School, Socorro, New Mexico. The solar system was designed to provide 3.55×10^8 Joules per day (3.36×10^6 Btu per day) or approximately 1,893 liters (500 gallons) of solar-heated water per day at 55°C (130°F). The heat exchanger was 55 meters (180 feet) of bare copper tubing. The tubing is 2.54 centimeters (1.0 inch) in diameter and it was placed inside a 946.3 liter (250 gallon) fiberglass storage tank having 1.5-inch polyurethane insulation.

Both analytic calculations and experimental results are presented and compared, and a thorough mathematical analysis of the model is also included. The analytic calculation were found to be in a good accuracy with the experimental results.

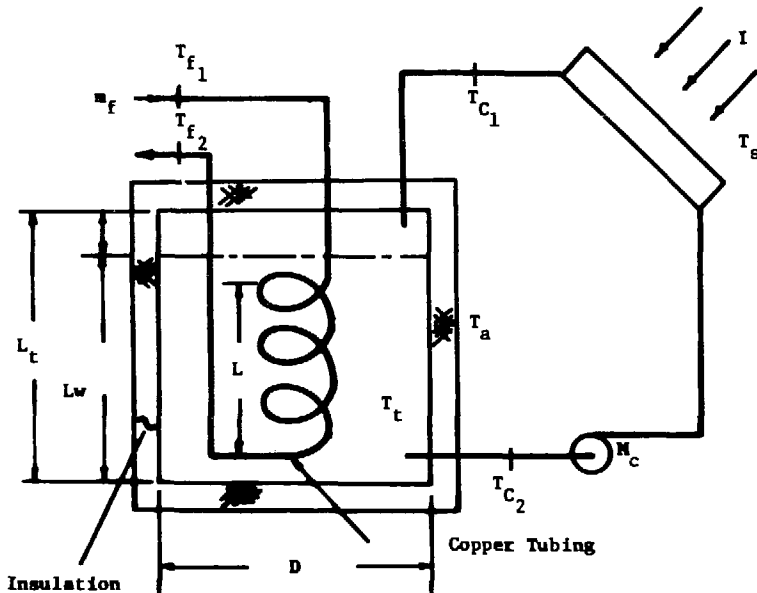


Figure 1. Schematic of the Solar Domestic Hot Water System Using Storage-Type Heat Exchange

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Abstract

A HEAT EXCHANGER STORAGE TANK

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The Delaware solar brooding system uses a hot water storage tank for storing solar heat collected by a medium temperature concentrating solar collector. The working temperature for the storage system ranges from 45°C to 85°C. By collecting and storing heat energy at these temperatures, the size and cost of the storage are reduced. Since the cost of the concentrating collector is comparable to that of flat plate collectors, the total system cost is reduced.

To further reduce costs the storage tank is constructed from corrugated steel grain tank rings and a flexible prefabricated liner. The uniqueness of the storage system is that the tank surface is used for delivering the heat from storage to the load. A plywood shroud encloses the tank from the floor to the ceiling and provides a 4 cm air gap between the tank surface and the insulation. A fan above the tank draws brooding room air in at the bottom of the tank and up along the tank surface. The heated air is then exhausted back into the brooding area and distributed by a center duct.

A model of the tank and shroud was constructed to verify the modeling equations and to determine the heat transfer coefficients for the storage system. The equations and results from the model were used to simulate the storage system in the computer program for the total brooding system. A prototype system is presently being constructed which will provide field verification of the model. A preliminary cost comparison shows this system to be preferable to a conventional finned tube heat exchanger and storage tank.

EARTH-AIR HEAT EXCHANGER

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EXTENDED ABSTRACT

Passive solar design may be compared to the use of a savings account which is used to balance withdrawals at times when the income is not sufficient. Storage, of course, is the savings and solar radiation is the income. Passive energy designers are aware that collection of solar energy alone does not provide uniform comfort in a dwelling space. Therefore most passive designers emphasize the storage mechanism within the building structure. However, most of these approaches ignore the fact that the earth itself already provides this storage capability in the form of a savings which can never be overdrawn.

In the context of passive design, the ecosystem should be viewed as a perfect example and generic model for passive systems with the earth providing the storage mechanism. The ability of the earth as the energy storage (heat source/sink, as well as insulation) can be effectively utilized in the modeling of passive energy systems.

The macro-climatical properties of earth (universal properties and principles) and thermophysical properties of soil, as micro-climatical parameters, can be integrated by means of an ancient passive system which evolved in Persian Architecture many centuries ago. This ancient passive system, defined as Earth-Air Heat Exchanger, is capable of meeting the entire energy demand for comfort conditioning (heating, cooling, and ventilation) within the dwelling spaces.

In this passive system, the mass earth itself collects and stores energy on a seasonal cycle rather than a daily cycle. The amplitude of earth temperature fluctuation decreases rapidly and exponentially with depth. At the depth of nearly three meters below the surface, the earth temperature approximates the annual average ambient air temperature of a given location with a small deviation.

The idea of using earth and utilization of her macro/micro climatical parameters is not new and has persisted throughout history and around the world. This paper looks thoroughly into ancient Persian Architecture for its use and utilization of earth-integrated passive energy structures.

Today, the use of a large volume of earth as an energy source is consistent with the ever increasing need to conserve the energy sources. The yearly average air temperature can be utilized in estimating the feasibility of an earth integrated energy system for specific locations. Therefore, by means

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of the heat transfer/exchange systems, it is possible to effectively utilize this permanent energy source available to us.

SINGLE-PHASE RESPONSE OF A PACKED-BED THERMAL STORAGE UNIT
TO A GENERAL VARIATION IN THE RATE OF THROUGH-FLOW

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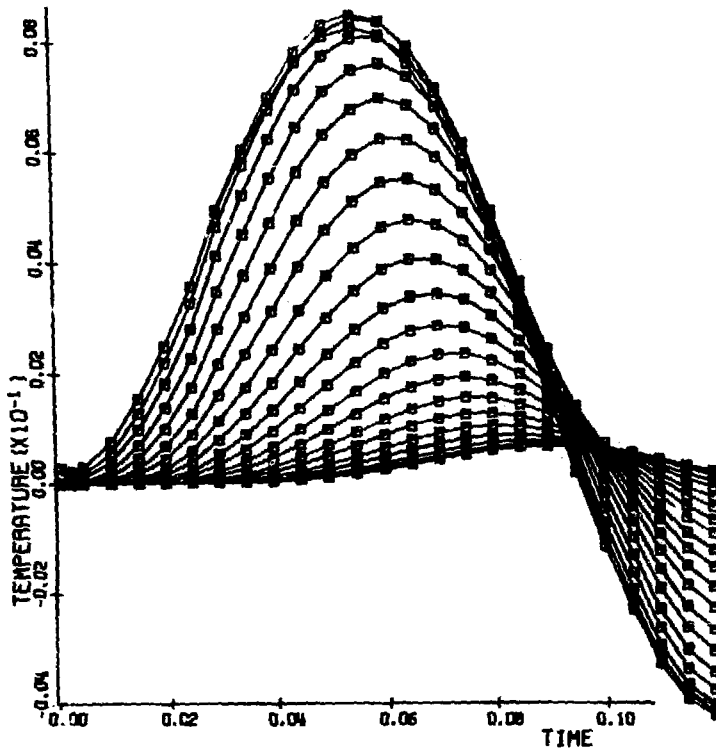
EXTENDED ABSTRACT

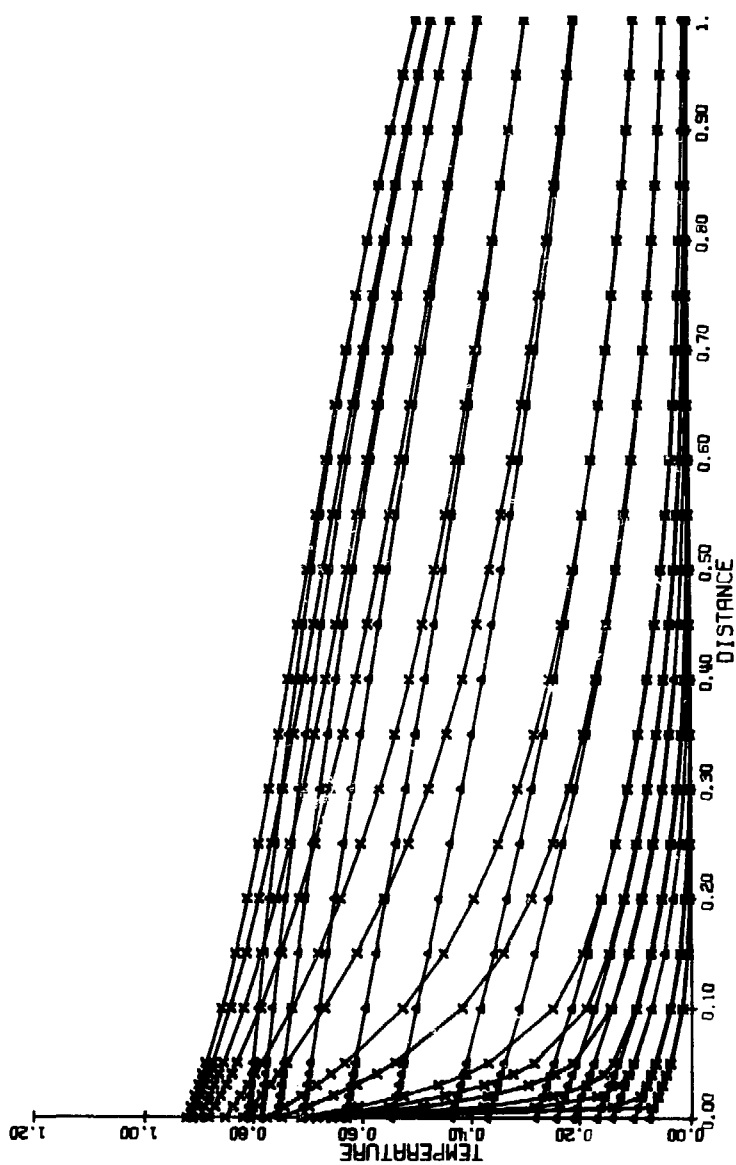
The transient temperature response of a packed-bed thermal storage unit, to a general (non-single blow) variation of the rate at which a fluid is being forced through, and considering the conductive effect in the bed, is analyzed using the one-phase model. The model is also supplemented by the discovery of a thermal boundary layer near the entrance, inside which the fluid temperature is drastically different from that of the bed, thus exhibiting effectively a two-phase response near the entrance. A hybrid analytical-numerical technique called the "non-final use" of finite integral transforms is recommended for the computer simulation. Detailed results for cases where the rate of through-flow either increases linearly from zero to a final value (which is then maintained), or hovers around a fixed (mean) value in a sinusoidal manner, are presented as practical examples. It is seen numerically that fast deviations from a single-blow application of the through-flow cause negligible changes in the thermal behavior of the porous medium; but deviations occurring at slower rates can render a prediction based on a single-blow analysis useless. The problem is formulated with heat conduction and energy storage in the fluid neglected; but the conduction and storage in the bed are fully accounted for. The major event happening in the fluid phase is the convective transport of energy downstream. The coupling of the two phases is provided by the inter-phase Biot number B which is assumed to be large. In the limit of B going to infinity, the single-phase model appears farther away from the entrance, which predicts the same temperature response for the fluid and the bed. Near the entrance, a boundary layer structure is displayed in the thermal history of the fluid, while the bed temperature turns out to be isothermal across the same layer. Thus, the single-phase response is judged uniformly valid (for large B) throughout the bed; yet, in the entrance layer, the fluid temperature behaves differently, practically forcing the issue of a two-phase response there. In the linearly varying case, compared to the associated single-blow operation, it is noted that the response lags behind by an extent of as much as 10% after a moderate time following the start. In the sinusoidal case around a mean value of the through-flow rate, a deviation of 4% is found, for a moderate frequency of hovering, at smaller time values. Possible extension and modification of the investigation are also pointed out at the end of paper.

Two sample plots that follow show the general trends of the numerical

results (all in dimensionless terms). The first shows the deviation of the single-phase temperature in the case of a sinusoidal through-flow hovering over an average value, from that based on a single-blow at the average value. The curve with the largest amplitude belongs to the entrance; while the one with the smallest, to the exit. The second figure shows the evolution of the temperature profiles for the linearly increasing case (reaching a certain final value which is then maintained). The curves marked with triangles represent the development of the bed temperature; those marked with crosses, the fluid temperature (with a thermal boundary layer near the entrance). The topmost curves are the steady temperatures; and the small-time solutions occupy the corner near the origin of the plot.

Our work was performed under NSF Grant ENG 78-04060.





THE USE OF MINIMUM VOLUME AND LOW COST MATERIALS
FOR SOLAR ENERGY STORAGE IN THE TEMPERATURE
RANGE 20 - 90 °C

By

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A new concept was used in the design of a storage unit to store solar energy in Paraffin Wax and a solution of calcium chloride and water utilizing their latent heat of fusion to store large quantities of energy in comparatively small volumes over a useful temperature range of 20 - 90 °C. The storage unit was of the radiator type consisting of copper pipes mounted inside a metal box. The spacings between the pipes themselves and also between the pipes and the internal faces of the metal box were so chosen to ensure uniform temperature changes throughout the whole storage materials. This new design overcame problems encountered in an earlier work by the authors.

A flat plate collector, previously designed by one of the authors was used for the experiments and proved very satisfactory.

Temperature values were recorded at the inlet and outlet of both the storage and collector units and also at various pre-determined locations along the units using thermocouples.

The results show that Paraffin wax with a melting point around 45 °C is particularly useful for hot climates such as Saudi Arabia and can be used advantageously throughout the year. Whereas the solution of the calcium chloride and water with a melting point around 30 °C is more beneficial to somewhat cooler climates and hence ideal during the winter months in this country.

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EXTENDED ABSTRACT

HIGH TEMPERATURE THERMAL STORAGE USING SLAG

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1. INTRODUCTION

Slag, or iron orthosilicate (Fe_2SiO_4) is a byproduct of copper smelting. An average size smelter produces more than 2000 tons per day of the material, which is usually discarded in its molten form at over 1400 C (2552 F) as solid waste. Several hundred thousand tons of slag are produced each day around the world. It currently has no value and is merely piled in mounds adjacent to smelters.

Because of the method of disposal, slag agglomerate particle sizes are generally in the range of 1 to 15 cm effective diameter. Once sized and classified, particles can be selected to be in an optimal range for use as a heat sink in packed bed thermal storage devices. Packed bed configurations can be designed for even heat distribution, low pressure drop for the working fluid, a steep thermocline in the bed, extremely large effective heat transfer surface area, and a high fill fraction (low void fraction). The material is dense and has relatively high thermal capacity. Its specific gravity is 4.3 to 4.4, and the specific heat ranges from 0.16 to 0.24 cal/gm/C over the range of 20 C to 1000 C. It remains thermally and mechanically stable in structure up to 1200 C, though tests indicate stability at even higher temperatures up to the melting point.

2. APPLICATION

The advantage to using slag in thermal storage devices is that it can be utilized at high temperatures, while remaining inert toward gases employed at those temperatures and remaining chemically, thermally and mechanically stable. Its potential for use in gas power cycles and industrial process heat applications is evident. Its low cost and high volumetric heat capacity could make it economical and feasible for use in any thermal storage application at any temperature up to 1300 C (2372 F).

3. CONCEPTUAL DESIGNS

Conceptual designs have been developed for slag packed bed thermal storage systems for both gas power cycles and high-temperature industrial process applications. In the former case, the packed bed is enclosed in a pressure vessel and is in series with a heat source (e.g., a solar receiver) and backup combustor placed between the compressor and turbine of a gas turbine. In the latter case, the bed is utilized at low differential pressure with respect to ambient, and is contained and insulated with compacted earth. The storage device for gas power systems could be utilized for both open and closed cycle gas turbines, at temperatures ranging from 650 C to 1200 C (1200 F to 2200 F), and pressures of 2 to 30 atmospheres (30 to 450 psia). The storage device for industrial process heat is proposed for an application in copper smelting, providing heated air at 540 C (1000 F) for a flash furnace. This concept was developed by G&H as part of the baseline design of a solar cogeneration system for copper smelting.

4. PERFORMANCE

The predicted performance of the slag packed bed thermal storage system is impressive. Using air as the working fluid, the thermocline in the bed is only a few meters thick, exhibiting a temperature delta of over 500 C (900 F). The pressure drop across a length of 30 meters in a bed 30 meters in diameter, packed with 2 to 6 cm agglomerates, is less than 25 mm Hg (0.5 psi) with an air flow rate of 6000 standard cubic meters per minute (210,000 SCFM). The storage capacity is sufficient to provide this flow at 540 C for up to three days at continuous discharge. Coupled with a high-temperature, high solar multiple, solar power system, virtually uninterruptible process heat is provided to the industrial facility year-round. The only moving parts in the system are the gate valves and compressor, and the storage device is extremely simple to construct, maintain and operate. Its reliability is high and predicted costs are extremely attractive.

5. COSTS

The slag itself is the most inexpensive part of a thermal storage system. Handling, transport, sizing and classification, and placement in the packed bed should cost \$10 to \$20 per ton. Piping for the above concept was estimated at \$1000 per meter, while earth moving (to insulate to a depth of 3 meters) was estimated at \$10 per cubic meter. The compressor, controls and valves add about \$200 per SCFM (about \$6 per SCFM). With a 50 percent contingency and fee for design and construction, a 20,000 m³ system would cost \$3.5 million, or about \$175/m³. The storage unit capacity, with a 500 C temperature delta, is

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2×10^{13} joules (1.9×10^{10} Btu). Therefore, its cost is \$175/GJ (\$184/MMBtu). This is an order of magnitude less than any other thermal storage device to our knowledge, even for lower temperature (<200 C) applications.

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SESSION 6A

PASSIVE SOLAR

COMPATABILITY AND COUPLING OF PASSIVE SYSTEMS

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EXTENDED ABSTRACT

Passive architectural design integrates consideration of form, space, and systems to produce a solution to human comfort and the needs for shelter. Passive design is composed of two complimentary paths of analysis and design: Micro-design and Macro-design.

MICRO-DESIGN

Micro-design is considered the step by step procedure of producing structures that are self-sufficient in meeting their energy demand for space conditioning by natural means. Therefore, micro-design is concerned with the maximum potential and optimization of geometrical, thermophysical and operational criteria within the socio-cultural envelope. These criteria should be optimized with reference to micro and macro climatical parameters and the pattern of use.

In the geometrical context [$f(l)$, as function of extension in space], design should be developed toward an optimized composition of passive forms and passive space modules. The composition must respond to the collection of input energy, geometrical factor (view angle), location of the collection mechanism, location and distribution of the storage mass, aspect ratio, and forms and spatial proximity and relation.

Thermophysical criteria [$f(m)$, function of mass] are concerned with the properties and thermal responses of matter: its' specific heat, its' density, its' conductivity, its reflection/absorption/emissivity characteristics, and its state as gas, liquid or solid.

The operational criteria [$f(t)$, function of time] are concerned with the properties of matter in motion; namely time and function. Operational criteria considers the use and operational patterns of spaces, forms, and infra-structures.

The composition of the optimized designs with respect to the above three criteria is considered as micro-passive design. This resultant is to provide a self-comfort condition for dwelling. Falling short in meeting the entire energy demand may be remedied by the use of complimenting passive systems, which are described in macro-design.

MACRO-DESIGN

Macro-design is concerned with integration of systems and components to meet that portion of energy demand not being provided by micro-design for comfort conditioning by natural means. The indoor comfort conditioning systems emphasize control over one or more of fundamental heat or mass transfer mechanisms: radiation, convection, conduction, or mass transfer. These space conditioning systems are classified as Passive, Hybrid, and Active systems. Passive solar energy systems are characterized by the fact that heat and mass moves through the system by natural means, that is without any parasitic and supplementary energy. Therefore in order to arrive at an entirely passive design, it is necessary that the resulting design, from micro-design procedure be supplemented with one or more passive solar energy systems.

This paper explores the methodology for passive micro-design procedure and examines the integration of this resultant design with one or more passive systems to meet the required supplementary energy demand. The ancient Persian Architecture is used to provide an existing example of totally energy self-sufficient architectural designs.

It is this author's belief that the structures can be designed to provide the entire energy demand for space conditioning by natural means through micro and macro passive design procedures and methodologies.

ATTACHED-SUNSPACE DESIGNS: A NATIONWIDE ECONOMIC APPRAISAL

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EXTENDED ABSTRACT

Performance estimates have recently become available for attached-sunspace passive solar heated residences [1]. Performance estimates have been made for an attached-sunspace with insulated end walls and night insulation. The sunspace has a single south-facing glazing plane tilted 50° from the horizontal. It is 9 feet high at the back wall and 11.5 feet wide. The length of the sunspace is varied to provide different levels of solar savings to the residence. The LASL/UNM EASEIII Model [2] is used to examine the economic performance of this sunspace design. The analysis is nationwide in scope; 220 regions are included. The results presented include design and economic performance indicators in both mapped and tabular form.

The LASL/UNM EASEIII Model is a tool which is used to evaluate the economic performance of passive solar designs. Region specific design performance estimates are combined with region specific fuel prices, residence design parameters, cost adjustments, state level incentive plans and nationwide economic parameters to calculate design cost and economic performance measures. The life cycle cost of the passive design is compared with the cost of a conventional heating system. This comparison is the basis of the net present value calculation, one measure of economic performance. Current fuel prices are used to calculate the first year value of the fuel which is displaced by the sunspace. The economic performance of the design is optimized by finding the sunspace configuration which minimizes the combined cost of conventional and solar heat delivered to the residence. The sunspace design is attached to a single story home. The economic analysis assumes that it is a retrofit design.

Maps 1 and 2 show the performance results for a sunspace which is of a fixed length--30 feet long (330 square feet of floor area). Solar savings fraction and conventional fuel displaced are displayed for 220 regions throughout the United States. The design provides relatively high solar savings fractions in the coastal and southern portions of the country. The performance is somewhat diminished in the interior and more northerly locations. The solar savings fraction is not a good indicator of the economic performance of the design by itself. The fraction must be combined with the heating load to determine the amount of conventional fuel the sunspace is displacing. Map 2 shows this information. Areas with very high heating loads show greater quantities of fuel displaced than areas with low heating

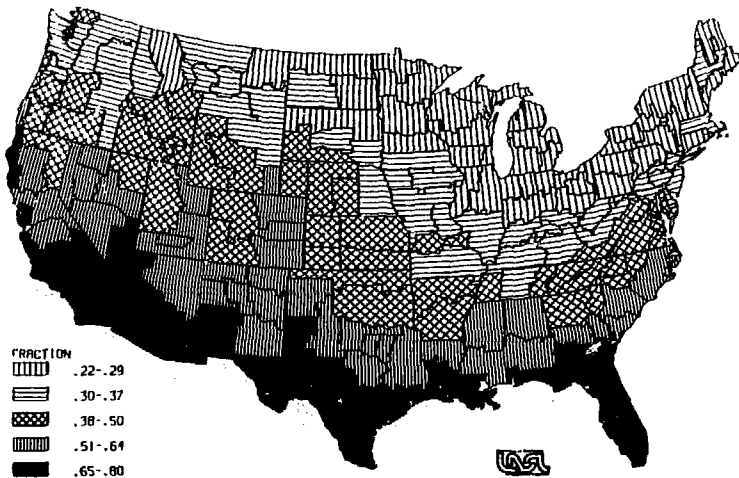
loads even though the solar savings fraction is lower. The regions in which the most fuel is displaced tend to be interior western locations. These regions combine the high heating loads of interior locations with the high solar savings fractions associated with high availability of winter solar radiation. The application of region specific fuel prices to the energy savings gives a value to that saving. As with other passive designs the economic performance of the sunspace is dominated by the relative level of conventional fuel prices. The sunspace competes very well against electric resistance but less well against the much cheaper natural gas in most regions.

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Map 1

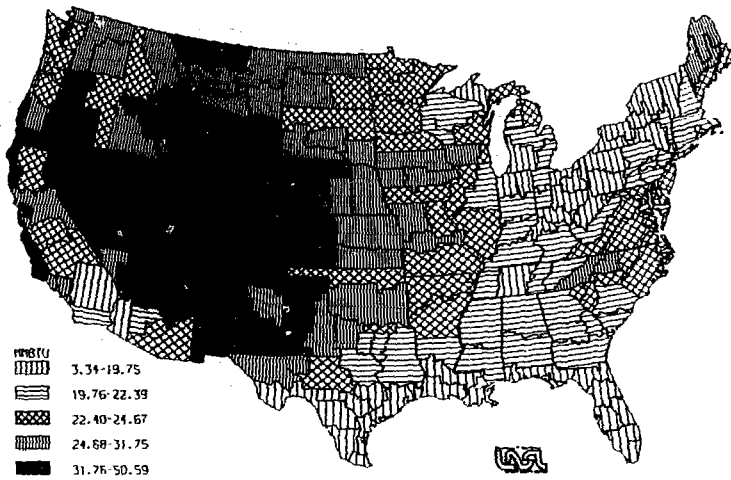
ATTACHED SUNSPACE SOLAR SAVINGS FRACTION SUNSPACE DESIGN INCLUDES NIGHT INSULATION



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Map 2

ATTACHED SUNSPACE SOLAR SAVINGS IN MMBTU
SUNSPACE DESIGN INCLUDES NIGHT INSULATION



CONTRIBUTION OF SOLAR PASSIVE SYSTEMS IN EDIFICATION

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EXTENDED ABSTRACT

INTRODUCTION

The development of this present study is based on the first step of the "Solar Houses Project" of the Mining Research and Investigation Center of Turkey. This step consists of the study on the direct capturing process of solar radiation by Trombe Wall's passive technique for supplying heating needs in edification. The overall strategy of the project is, at first, to determine the feasibility of employing solar energy for heating buildings and secondly, to develop and test the reliability of the heating system which fits best to Turkey's economic restrictions.

The purpose of this paper is to report the measured performance of the passive system under the Mediterranean climatic conditions and to widely disseminate the results.

DESCRIPTION OF PROJECT

Turkey is an active member country of the NATO-CCMS Solar Energy Pilot Study. In this respect, a national solar heating and cooling project has been formulated and put forward in four phases, with major efforts devoted to solar heating and cooling of the following four types of houses, appropriate to the current conditions of Turkey: [1]

- 1-Village houses with no water and electricity; heating
- 2-Village houses with electricity but no water; heating
- 3-Small dwellings with both water and electricity; heating
- 4-Buildings, schools etc. ; heating and cooling

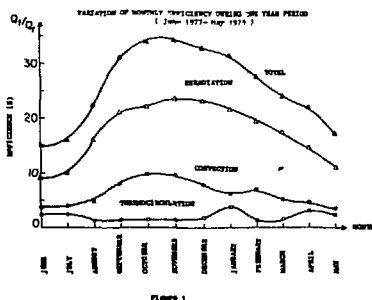
The first phase of the project aims at developing a passive

solar heating system. In order to establish criteria for initiating and supporting solar house project, a house utilising the Trombe-Wall principle for heating purposes has been constructed [2,3]. A data gathering and register equipment has been installed inside. Close to this solar house a reference house is built. The system has put into a operation in June, 1977 and related measurements have been going on. Simultaneously the energy balance and annual efficiency of the solar heating system were calculated at the "Optics Institute of C.S.I.C." in Madrid, for a one year period (1977-78 June) using the experimental data obtained in "Marmaris Solar Energy Research and Investigation Center of M.T.A." in Turkey [4].

In this process of solar heating all the functions of the solar system collection, storage, distribution, control and regulation are located in the south facing wall of the building and practically inseperable. The util energy is transferred by reradiation, conduction-convection and thermo-circulation. A computer simulation analysis has been employed to aid in the tabulation of hourly, daily and monthly transferred energy and solar fractions which correspond to heating load of the house. Monthly efficiencies have been established from these tables and the following results and conclusions have been obtained.

RESULTS AND CONCLUSIONS

1- The experimental solar house (habitable area=56 m², wall area=17.5 m², volume=135 m³) reflects the economy obtained by heating: (Table I and Figure 1)

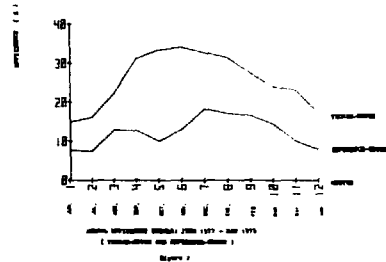


DATE	SOLAR	REFERENCE	DIFFERENCE
1977 June	14.90 %	7.58 %	7.32 %
1977 July	16.16	7.51	8.65
1977 August	22.24	12.89	9.35
1977 September	31.08	12.76	18.32
1977 October	33.85	10.21	23.64
1977 November	34.06	13.04	21.02
1977 December	36.65	18.26	18.39
1978 January	31.38	17.10	14.28
1978 February	27.42	16.50	10.82
1978 March	23.86	14.37	9.49
1978 April	21.96	9.98	11.98
1978 May	17.27	7.92	9.35

TABLE I

2- The distribution of annual solar fractions in the solar house are: by reradiation(68.04 %),convection(23.51 %), circulation(8.45 %) with respect to the reference house.

3- If the reference house is considered as another passive system like as a "direct gain" type with 2,92 m² glass area on the south facade, a more useful energy can be obtained. (Figure 2). All these percentages correspond to the heating necessities at Marmaris which has a following geographical characteristics, (Latitude= 36° 47' N ; Longitude= 28° 02' ; Altitude= 30 m. from sea level ; Zone=Egypt Coast)



All these calculations and experiments allow to acquire information on the performance and suitability at this kind of solar house within the Mediterranean climatic conditions.

Finally, we can affirm that development of accumulation wall type passive systems will permit us the following advantages; simple construction, free maintenance, cost reduction, thermal comfort by natural operation and reliability.

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THE NEGLECTED BUT NOT FORGOTTEN ART
OF SUN PORCH SOLAR HEATING

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Abstract

History - Sun Porches have been a source of residential solar heat for more than 2,000 years. The Romans first developed the Hella Caminus, a type of Semi circular Sun Porch with vertical glass facing the sun from East to West. (See slide of semi-circular sun porch) Since then the more common rectilinear Sun Porches flourished as an important feature in French, German and English Vernacular Architecture. In 18th & 19th Century colonial America Sun Porches were a common feature, used to warm up the large mansions of that era. Examples of American SunPorch Architecture (see slide presentation) generally indicate a south eastern exposure. This was important to provide sun heat in the early morning when homes were cold and fires had burned out. The 20th Century Era of Cheap Energy has all but erased the use of Sun Porches as a means of home heating but the use of glass enclosed porches is still common for growing plants, although most are not properly designed for solar heating.

Traditional Sun Porch Design - The architectural aesthetics of Sun Porches balance perfectly with the colonial American architecture that provides the basic form for most of the residential homes in the U.S. The gabled roof has traditionally been used in two different forms to attach a Sun Porch onto the South or East sides of a home. The more classic form is the Gable End Porch. (Illustrated by slide of Hill Crest Manor) The other common form is the shed roof porch common to country farm houses. (See slide.) Traditionally the glass walls of Sun Porches consist of a row of tall double or triple hung windows, which are operable to allow for summer ventilation. Unfortunately, these windows also allow infiltration of cold air. This plus the general lack of thermal storage makes the Sun Porch inhabitable only when the sun is shining. However, even these single glazed, uninsulated porches collect a large amount of Solar Energy.

Functional Use - Aside from its use as a solar heating device, the Sun Porch offers excellent recreational opportunities. It can be used for sun bathing, indoor recreation games, children's playroom, hot tub bathing, sauna or greenhouse.

Sun Porch Thermal Flow - The classical sun porch generally has two or more large french doors which can be opened to the house so that the heat of the Sun Porch can come in. Modern air distribution techniques improve upon this use of the Sun Porch as a hot air collector by circulating hot air and replacing it with cool air from the house. Natural convection is the most effective method, if it is properly designed. By placing a row of vents at the ceiling and another row with dampers at the floor an air circulation pattern is set up where the hot air rises through the high vent which draws cool house air from the lower vents to replace it. (See illustration.) The resulting air circulation will transfer comfortable useful heat with as little

as 10°F between the Sun Porch and the living space. Fan forced air circulation is advisable when floor and ceiling vents are not practical. This method can move a large volume of air through a small opening such as a window. The air in the Sun Porch must be between 85° to 95° depending on fan velocity in order to provide comfortable air to the living space. At lower temperatures the cooling effect of the moving air makes it uncomfortable. This lower temperature heat is not wasted, because it provides a tempering effect warming the wall and reducing the heat loss of the house. This effect can be increased through the use of adequate thermal storage.

Summer Cooling - Traditionally most of the windows in a Sun Porch were operable for ventilation during the summer. It is necessary to provide at least 1/6th of the glass area in operable vents, which can be cross ventilated side to side or bottom to top. The sun porch does not have the severe summer overheating problems of a greenhouse because of its insulated opaque roof and the high angle of the summer sun. Thus, the sun is shed away from the house so that the south wall of the house is cool and shaded. Additional cooling devices can be built into the porch. For example, the Sun Porch can be used as a thermal chimney to draw air from the house and replacement air can be provided by conductive cooled air. A similar system was incorporated into my Cycle 5 house except that it used a fan to move the air.

Solar Options - Modern Sun Porches, using the latest engineering and products technology have been able to make giant strides to increase the effectiveness of Solar gain. This is accomplished through the use of highly transparent insulating glazing, moveable insulating shades, and properly designed thermal storage.

Old fashioned glass was imperfect and unclear. It had a high iron content which reflected or absorbed all but 69% of the sunlight in a single sheet. Now, low iron double insulating glass panels are available which allow passage of up to 75% of the available sunlight. Also many other glazing materials such as Double Skinned Acrylic and Fiberglass Panels are available with light transmissivity of up to 83%. These plastic glazing panels are useful in high density areas where privacy is a concern because of its light diffusing characteristics. However, this is a disadvantage on historic homes due to the non-historic appearance of the material.

Moveable insulation has its historic roots in wooden storm shutters and heavy thermal drapes. Modern innovations have made high quality thermally efficient shades commercially available, and a necessity for passive solar heating. By reducing night time heat loss, you can maintain a higher temperature in the Sun Porch which means that more useful heat will be radiated to the house at night, and temperatures in the heating range of 70° to 90° will be achieved much faster on sunny days. Similar results may also be obtained by using triple, and quadruple glazings. This technique was applied to the end walls of the Solar Log Home that is the Office of the Solar Design Studio, so that eastern sunlight would be unobstructed by shades in the morning and western sun in the evening.

Storage is an important feature which was completely lacking in traditional architecture, with the exception of uninsulated solid brick & stone masonry.

Properly designed storage should provide mass of water, stone, concrete or salt hydrate, directly radiated by the sun, in quantities adequate to provide 45 + BTU's of storage per Square Foot of Glazing per °Fahrenheit. (see illustrations of each storage method from Sun Porch Design Manual.)

New England Log Homes Inc. Two of the Six Sun Porch solar heated homes that have been designed by the Solar Design Studio are Log Homes by NELHI. One of these projects is the office of the Solar Design Studio & Associates (See Photo.) and the other is a HUD Cycle 5 award home that was designed, built and sold by the Solar Design Studio with assistance from their associates. These homes have been built to exacting standards using every energy conserving feature possible. Test results will be available in the Spring of 1980, but calculated performance data suggest that at least 67% of the heating requirements of these buildings will be supplied by the Sun Porch Passive Solar Heating Systems. (The enclosed table of Contents is for the New England Log Home Solar Design & Energy Conservation Manual, which is currently being prepared and will be available for the 1980 Solar Conference.)

Conclusion - Sun Porches are aesthetically adaptable and easy to add as a retrofit to any existing house or house plans for new construction. In its simplest form as just a glassed in porch, it can operate effectively as a hot air collector. In its most efficient form, it can provide complete solar storage and insulation to maximize an effective passive solar heating. The Sun Porch overcomes several of the problems associated with Greenhouse Solar Heating: ie. there is no moisture, mold or mildew problem, no excess summer heat gain, and no plants to shade the thermal storage. Also, since it is designed specifically for Solar Heating it is eligible for Federal Tax Credit. There are many advantages to Sun Porch living, such as; cutting down of energy cost and consumption, having extra living space for recreation, but most important is the development of our awareness of the Sun, the ultimate source of all energy on Earth.

PASSIVE COOLING : TRADITIONAL CLIMATIC DEVICES IN SAUDI ARABIA

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Extended Abstract

The traditional architectural design concepts, forms and details show phenomenal climatic response in the vast desert environment of Saudi Arabia. The traditional design methodology and passive climate control systems are analysed in the hot-dry, hot-humid, composite and upland climates. Various scientific climatic concepts and details such as "the Liwan, Hawi or Finna, Khalwa, Satieh, Rowshans, Mashrabiya, Ba-duqayr" show passive cooling design methods useful in the present context. Comfort conditions during varying climatic conditions and diurnal changes are discussed.

In hot-humid Jeddah the houses are upto six stories high, do not have courtyards, use "Rowshans" (projected decorative bay windows) for maximum ventilation and "Mashrabiya" for achieving comfort conditions. Thick walls sometime tapering towards the top provide the required time-lag. Terrace sleeping is considered undesirable.

In hot-dry Riyadh the courtyard becomes the centre of focus in a thick walled house with very little external fenestration. Maximum number of doors and windows open under protection of collonaded passage around the courtyard. Courtyard provides the coolness from the cool night air which is filled in the rooms to keep them cool during the day. Thick walls provide the required time-lag. Poor air-change and lighting conditions are observed in some of these houses.

Similarly, entirely different forms of tall mud and stone structures tapering to the top are to be found in uplands of Asir province and conical mud-plastered thatched roof structures with African influence are observed in the hot-humid regions of Jizan. Several of such typical buildings are described in detail.

The traditional concepts of planning and urban forms show similarities found in comparable climatic regions in other parts of the world. It is recognized here that the dominance of religion created certain type of organization and need for privacy resulted in special details in the micro-environment of the rural or semi-urban layout. The Islamic city or town also developed with centrality of mosque, the market-place (souq), khans and hammams surrounded by housing and other services. However, in the organization of these basic elements of Islamic cities the climatic conditions seem to dominate the overall fabric of any small or large

development. The Islamic town development was not based purely on religious requirements but affectively took into consideration the climatic and geographic elements of the region. Special details such as narrow dead end streets with irregular layout provided protection against dust storms. Very narrow streets with hardly any passage from outside allowed the dust storms to pass over a development rather than through it. Narrow streets and overpasses also provided protection against the sun in hot-dry areas. In Riyadh or Qatif one finds mud-houses built close together sharing two or even three walls in large continuous lumps. Thus, most of the houses remained protected along with the help of the narrow streets from the sun. The sun penetration was only limited to courtyard during the afternoons. On the other hand, in Jeddah the houses are set far apart, free-standing where possible and taller rather than of low spread with more regular and wider streets allowing the air-passage for through ventilation in the hot-humid region. In uplands of Asir the houses are set on the sunny side of the hilly terrain to gain maximum insolation, set close to each other, and built of thick stone or mud wall to retain sun's energy during colder periods. These characteristics are comparable to hill towns of Italy or the first stone dwellings built by American Indians in California. Some of these climatic characteristics of individual buildings and urban layouts are discussed in this paper.

THE NEUTRAL ZONE IN PREDETERMINING NATURAL VENTILATION

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EXTENDED ABSTRACT

INTRODUCTION

Natural ventilation for the displacement of air in buildings can be produced thermodynamically by employing the heat generated from the processes contained within the building or aerodynamically due to the wind. This paper presents a method for predicting the flow of air into, through and out of a building by thermal means alone. Control of air flow due to thermal means is concerned with the sizing of air inlet and outlet openings. The concepts presented utilize ordinary laws of fluid flow to determine the volume of air movement for any distribution of area or window openings. Or the area openings can be determined for a desired quantity of air flow. The method presented is a result of efforts to shorten the somewhat lengthy trial and error method of calculating thermally produced air flow as developed in the research investigation conducted under the direction of Prof. J.E. Emswiler and reported in his paper "The Neutral Zone in Ventilation." [1]

THE NEUTRAL ZONE

In a building where the air inside is warmer than that outside, differences in pressure exist across the exterior wall and the pressure varies in intensity and direction at different levels from the floor to the roof. The level at which the pressure changes from less to greater than atmospheric is the Neutral Zone.

The pressure difference or head at any level varies directly with the vertical distance of that level from the Neutral Zone and flow through an opening is proportional to the square root of its distance from the Neutral Zone.

THE LOCATION OF THE NEUTRAL ZONE

If the location of the Neutral Zone could be calculated in advance it would be easy to determine the flow at any opening

by means of the equation

$$Q = 8 AC \sqrt{\frac{ZD}{T}}$$

where

Q = flow or volume of air in cubic meters per second (cubic feet, per second),

A = the area of an opening on square meters (feet),

C = a coefficient expressing individual peculiarities of the opening, dimensionless,

Z = distance of opening from the Neutral Zone, meters (feet),

D = $t_w - t_c$, difference in temperature between the warm air (t_w) and the cool air (t_c), °C (°F),

T = $\frac{t_w + t_c}{2} + 273$, average absolute temperature of the warm and cool air, °C (°F).

Note: When British units are used, constant 273 for the absolute temperature T is replaced by 460.

This writer has found a direct method of predetermining the location of the Neutral Zone, improving that procedure found by Prof. Emswiler. Prof. Emswiler's paper for locating the Neutral Zone and determining flow rate is, generally speaking, unwieldy and time consuming. Furthermore the Neutral Zone location is obtained simultaneously with flow rate and therefore is not instrumental in determining speed of flow. The method to be presented separates this operation while simplifying the calculation.

Given that

Z_1 = distance of lower opening from the Neutral Zone, meters (feet),

Z_2 = distance of upper openings from the Neutral Zone, meters (feet),

Z' = vertical distance between the upper and lower openings, meters (feet),

L = area of lower opening, meters² (feet²),

U = area of upper opening, meters² (feet²),

the distance of the Neutral Zone from the lower opening is

$$Z_1 = \frac{L^2 Z'}{L+U^2}$$

and the distance of the Neutral Zone from the upper opening is

$$Z_2 = \frac{U^2 Z'}{L+U^2} .$$

Hence, the location of the Neutral Zone can be predetermined given the area of the inlet and outlet opening and the vertical distance between them

The concept of the Neutral Zone (which applies almost equally well to the flow of water in thermosyphon heating systems, and air in gravity heating systems) assists in clarifying the problems of infiltration of air through the walls of buildings. In general, it is a valuable instrument for working with the principles underlying the flow of air due to differences in temperature.

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EXPERIMENTAL EVALUATION OF MULTI-PASS SOLAR AIR HEATERS

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EXTENDED ABSTRACT

INTRODUCTION

In an earlier paper[1], it was shown that the conventional two glass cover air heater when operated in the two-pass mode gave a superior performance to that when operated in the single pass mode. This paper extends the above work to the simultaneous testing of three conventional collectors of identical dimensions but operating in the single pass, two-pass and three-pass modes respectively. Each collector consisted of two glass covers, one blackened absorber plate and a rear plate. The length of each collector in the direction of flow was 1.22 metres (4 ft.) with the width being 0.91 metres (3 ft.) whilst the spacings of the three parallel plate channels formed by the glass covers and metal plates were each 4 cm.

In the single pass collector, the air was made to pass through the channel formed by the absorber and rear plates whilst in the two-pass collector, the air was first passed through the channel formed by the two glass covers and then through the channel formed by the rear and absorber plates. In the three-pass collector, the air was first passed between the two glass covers, then through the channel formed by the second glass cover and the absorber plate and then through the last channel. These three collectors were tested simultaneously.

RESULTS

It was found that the efficiency of the two-pass collector was consistently higher than that of the single pass collector, for all flow rates and over the day, by some twelve to fifteen percent. The efficiency of the three-pass collector, though higher than that of the two pass collector at high flow rates and over the day by some five to seven percent, showed no significant increase over that of the two-pass collector at lower flow rates.

For example, at a flow rate of $0.0095 \text{ kg/sec m}^2$ the two-pass collector has an efficiency of 13-18 percent higher than that of the single pass collector, whilst the efficiency of the three-pass collector is almost identical to that of the two pass collector.

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OPTIMIZATION OF THE PERFORMANCE OF SOLAR AIR HEATER

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ABSTRACT

Some possible applications of solar energy (e.g dehydration, space heating and cooling) require heat at moderate temperature. collection of temperatures in this range could be obtained using flat plate collectors using any fluid as water or air as heat carriers.

A theoretical study of the performance of the solar air heater have been made. The study have been performed, considering in particular the design and optimisation of the air collector operated by solar energy.

The design and optimization of the performance of an solar air heater depends mostly on the tilted angle of the collector, the amount of the incident radiation and the type of the collector. Optimization of the heat losses and efficiency of the collector was also performed. A computer program was written and run for different air spacing , glass thickness, collector length , and air velocity. In order to define the effect of the thickness of air spaces on the coefficient of performance of the collector the calculations were based on a constant rate of flow of air. The analysis and optimization were made for a steady condition.

ABSTRACT

Installation for Thermal Performance Testing of Solar Domestic Water Heating Systems

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Testing Installation

An installation was built at New Mexico State University for thermal performance testing according to ASHRAE Standard 95P [1] of packaged solar domestic water heating systems (SDWH) which use up to 0.38m^3 (100 gal.) of hot water per day. A schematic diagram of a portion of the test installation, (the supply water conditioning subsystem), is shown in Figure 1. The installation consists of two testing stands operating side by side, one is utilized to test liquid type SDWH systems and the other one to test air type SDWH systems. Tests are conducted indoors by using a thermal input to the system to simulate the solar radiation collected normally by the collector array. To provide this simulation an electric heating element sized to deliver the peak rate of available outdoor solar energy is employed. The energy input to the simulator is changed manually every 30 minutes throughout the test day by means of a variable auto transformer. The time constant of the simulator is less than 2 minutes. A modification of the installation is planned to allow testing, wherein solar collectors are included in the loop with thermally simulated collector input. This configuration is shown in Figure 2. A bypass loop with pump and valves, and an electrical interface controlled by the SDWH system controller provides heat to the collector from the solar heat simulator when the SDWH controller turns off the installation pump during the period of solar radiation simulation. By energizing the bypass loop, the collector temperature is made to rise until the controller turns the pump on again. Two water tanks, one with chilled water of 80 gal. capacity and another one with hot water of 42 gal. capacity are used to supply constant temperature inlet water to the system under test. All piping in the testing installation is insulated to comply with the standards and manufacturers' requirements.

Testing Procedure

The SDWH system is supplied by the manufacturer and assembled following his instructions. The collectors will be mounted 45° from horizontal. A radiation shield will be placed 2 ft. above the collector array, painted flat black and extending 2 ft. on all sides.

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** New Mexico Solar Energy Institute

Testing is conducted according to the requirements of the ASHRAE 95P draft or other procedures as applicable. Tests are conducted indoors in an environment that is controlled at $20 \pm 2^{\circ}\text{C}$ ($68 \pm 3.6^{\circ}\text{F}$). Basically, the system under test is purged of air, energized, and allowed to stabilize. Scheduled withdrawals from the system are made and measured to determine the ratio of the water heating load to the non-solar energy input, until agreement within 5% is achieved with the previous day's withdrawals. A final continuous draw test is made to determine the solar only hot water delivery capability.

The daily system hot water load (Q_L) is calculated from the total mass of water withdrawn and the temperature difference between withdrawn and inlet water. A figure of merit for the system called the energy multiplier (E.M.) is then calculated as the ratio of Q_L to the total energy input to the SDWH system's auxiliary heaters, pumps, controls, etc.

Measurements

During the test periods, measurements of the daily energy consumed by the SDWH system circulation devices (pumps, controls, solenoid valves, etc.) and the integral auxiliary heating elements are made. The daily energy input to the simulator is also measured. All data are recorded at 8:00 a.m. each SDWH system test day. During the withdrawal periods, the temperature of the incoming water and the temperature of the withdrawal water are measured every minute during the draw. The ambient temperature and the water temperature at the inlet of the collector are recorded every 30 minutes while the simulator is energized. Temperature measurements are performed in accordance with ASHRAE Standard 41.1-74 [2]. Pressures are measured as described in ASHRAE Standard 37-69 [3].

A standard collector test report utilizing the ASHRAE Standard 93-77 [4] test procedure is required for the system collectors. This report data is utilized to determine the daily input to the solar thermal simulator which is adjusted every 30 minutes.

Details of the test installation configuration as well as details of test procedures and methods of calculating performance are presented in the full paper. The paper will also discuss the test results for several solar domestic water heating systems.

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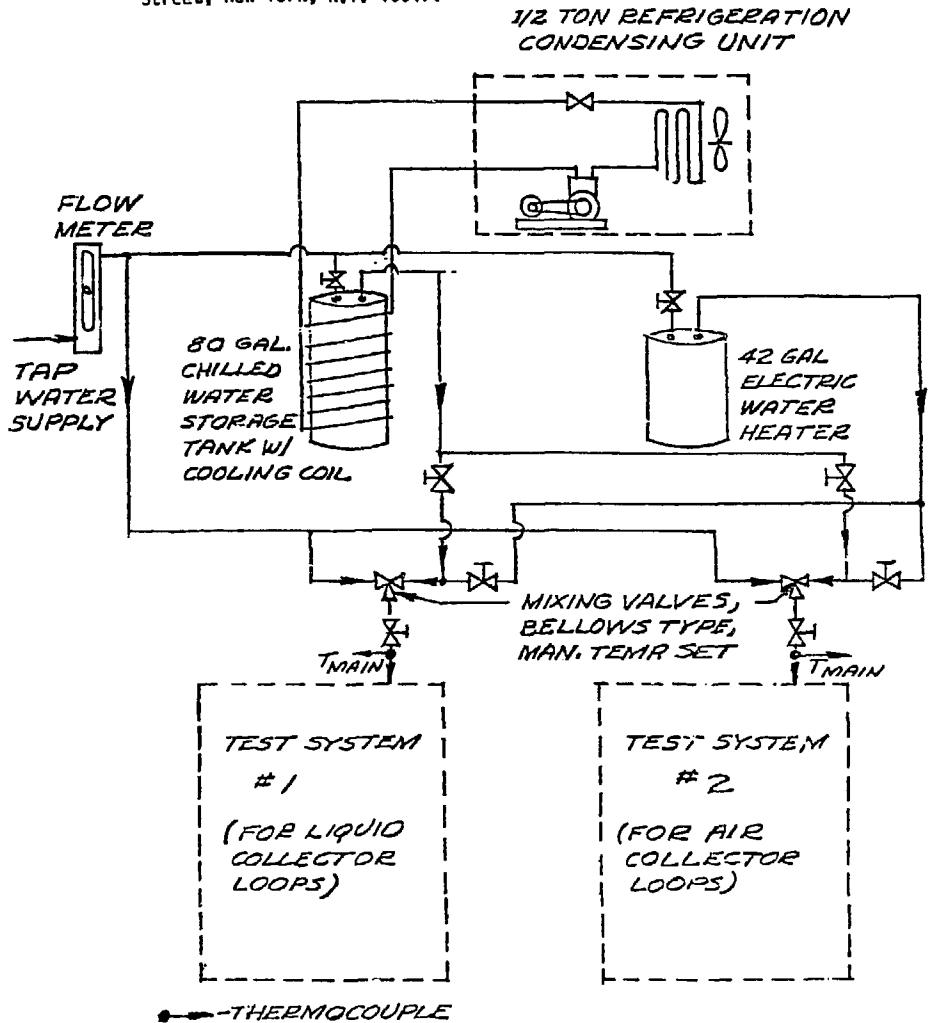
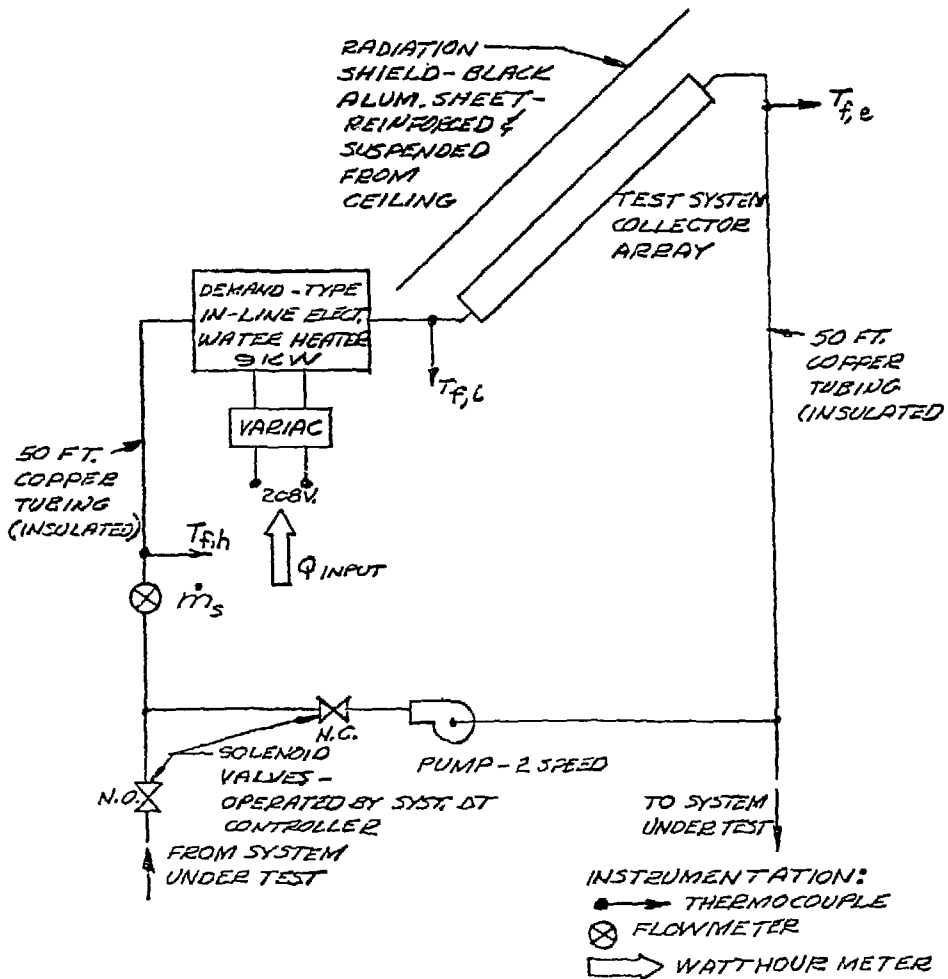


Figure 1. Schematic Diagram of Water Conditioning Subsystem of Test Installation



AN EXPERIMENTAL INVESTIGATION ON THE THERMAL PERFORMANCE OF
A FORCED CIRCULATION SOLAR WATER HEATING SYSTEM

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EXTENDED ABSTRACT

Work reported in this paper deals with both theoretical and experimental investigation on the thermal performance of a forced circulation solar water heating system with particular reference to stratification in the storage tank. For this purpose, a solar water heating system was constructed in the Solar Energy Laboratory, Indian Institute of Technology, Madras. A G.I. corrugated sheet flat plate collector of one square metre absorber area of channel width to spacing ratio of 0.6, and 6 mm channel depth, one glass cover and 5cm thick glass wool insulation for bottom and sides, is employed. The collector is tilted 11.8° to horizontal facing south, and connected through well-insulated $\frac{1}{2}$ inch I.D. pipes, and a circulation pump to a storage tank of 40 cm diameter and 100 cm height. The storage tank is insulated with glass wool 10 cm thick, and equipped with a float chamber to avoid any internal flow disturbances. The set-up is suitably instrumented to measure the average plate temperature, the temperature distribution along the tank axis, and flow rate in the collector circuit. Also, the ambient conditions and solar insolation are recorded at one-hour intervals.

The thermal performance and tank temperature distribution (effect of stratification) and, response to changing flow rates have been investigated. The system is filled up with fresh water for each run. The experiments were conducted on clear-sky days for different flow rates.

Results show that for no-load condition, there exists a range of flow rates (30 to 50 kg/hr.m²), during which the mean tank temperature attains a maximum value. Thermal efficiency, which is defined, here, as the ratio of the increase in the stored energy of the system in a certain period of time, to the total solar insolation striking the

tilted plate of the collector during the same period of time, also shows a maximum value for that range of flow rates. It was also observed that the average plate temperature and hence the energy losses show a minimum value for the same range of flow rates. For flow rates greater than 50 kg/hr.m^2 , recirculation of hot fluid from the tank during the forenoon keeps the collector plate temperature at higher value during most of the day. It was also seen, that the temperature difference along the tank axis (stratification effect), shows a maximum value at flow rates less than 30 kg/hr.m^2 , particularly during noon hours. At much higher flow rates, for example, at 80 kg/hr.m^2 , stratification effect is seen to be totally absent.

The above system has been examined theoretically by using a 5-segment stratified tank model for the same ambient conditions. Theoretical predictions show that, for high flow rates, the mixing in the storage tank attains a condition so as to make the temperature difference along the tank axis negligible, indicating complete loss of stratification. This is in consonance with observed experimental data.

Results, reported here, could serve to provide guide lines for adjusting the flow rates, so as to get the benefit of stratification in the storage tank.

PARAMETRIC STUDIES OF A NOVEL SOLAR WATER HEATER

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Effect of varying weather conditions on the performance of collector/storage water heater; which was developed earlier by Garg (1) where the absorber performs the dual function of absorbing the solar energy and storing the heated water; is further extensively studied both experimentally and theoretically.

Solar water heaters of the built-in-storage type incorporating the storage volume and collector in a single unit are cost effective and may well remove aesthetic objection of rooftop installations. This solar water heater performs at a very high efficiency reaching upto 70 per cent during the day time but its performance is adversely affected by significant night cooling. The performance of this heater during the day time as well as during the night time can be improved by providing a baffle plate in the storage tank. The aim of this attempt is to optimize the collector configuration to predict the storage water temperature under different climatic conditions and collector characteristics.

In the transient analysis the thermal capacity effect of cover glass, absorber plate, water, enclosed air and insulation; conduction loss effect of absorber plate, glass cover and insulation together with other heat transfer coefficients are taken into account. A two dimensional heat

transfer model is developed which accounts for various collector and environmental factors. The model is derived by performing an energy balance on each component of the collector, as the energy balance eq. on cover glass is

$$\dot{q}_g I = m_g c_g \frac{dt_g}{dt} + K_g \delta_g \frac{d^2 t_g}{dx^2} + h_{c,gw'} (t_g - t_a) + h_{r,gw'} (t_g - t_s) + h_{c,ag} (t_g - t_a) + h_{r,pj} (t_g - t_p)$$

where, the left hand side denotes the net radiation absorbed by the cover glass plate, the first term on the right hand side accounts for the heat capacity of the glass plate, the second term presents the conduction loss along the flow direction of the cover plate, the third term represents convection to the atmosphere from cover glass plate, the fourth term is the radiation exchange between the sky and the top of the cover, fifth term is the convective heat transfer between the enclosed air to the cover glass, the last term is the radiation heat exchange between the cover glass and the absorber plate. On the other collector nodes also the energy balance equation can be written in the same fashion.

The above set of equations is solved by using finite difference technique. In the finite difference scheme the derivatives are replaced by the difference approximations of the form

$$\begin{aligned} \frac{\partial t}{\partial x} &= \frac{t(i+1, j) - t(i, j)}{h} \\ \frac{\partial^2 t}{\partial x^2} &= \frac{t(i+1, j) - t(i, j) + t(i-1, j)}{h^2} \\ \frac{\partial t}{\partial a} &= \frac{t(i, j+1) - t(i, j)}{k} \end{aligned}$$

where h and k are space and time increments.

For the instantaneous prediction of ambient temperature and solar radiation Fourier Series is used (2). Experi-

mentally also solar radiation and the ambient temperature are recorded by Kipp and Zonen pyranometer connected with automatic strip chart recorders at IIT Delhi.

If we cover the system with insulation during night time, then the fall of temperature during night time becomes much slow, and even in the early morning hours the stored water can be used for bathing and for other domestic applications. Studies on this and on the use of baffle plate are in progress at IIT Delhi.

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A NOVEL SOLAR WATER HEATER

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ABSTRACT

This communication proposes a novel solar water heater which is essentially a rectangular metallic (G.I.) tank with an inlet and outlet respectively for cold and hot water. The tank (filled with 90 litres of water) is buried on the ground; the depth of the burial can be varied depending on the requirement of hot water. The top surface of the ground is blackened and glazed so that the surface acts as an absorber of solar radiation while the tank as well as the surrounding earth serves as a storage system. A part from being protected from the weather conditions, this water heater is prevented from rapid temperature fluctuations (which occurs predominantly in West-Asian deserts) and its cost is reduced significantly since no insulation is required to be used. The transient behaviour of such a water heater has been presented so as to evaluate its performance. The depth of the tank can be varied to achieve a specified maximum water temperature at a stipulated time.

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SESSION 2B

HEATING AND COOLING

VARIOUS STRATEGIES CONCERNING SOLAR HEATING FOR
A BASEBOARD HOT-WATER HEATING SYSTEM

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EXTENDED ABSTRACT

It is well known that a flat plate solar collector system can be used to provide a portion of the space heating requirements for homes in the North-Eastern portion of the United States, provided that the back up system is an air to air system or a water to air system. Various sizing methods, such as the well known f-chart method, can be used to determine the usefulness of such solar systems on various homes. However a large portion of homes in the North-East use an all water baseboard space heating system and the use of solar in conjunction with such a system is severely limited by the relatively high operating temperature of the boiler (60°C-80°C). The efficiency of flat plate collectors falls off appreciably at these temperatures and the fraction of heat supplied by solar becomes small.

However recent experiments on baseboard hot water heating systems have shown that the operating temperature of the boiler can be lowered for many days during the heating season and still provide sufficient heat. For example when the outside ambient air temperature is 0°C a boiler operating temperature of 40°C to 60°C can provide sufficient heat for a typically insulated house. There are now available off the shelf computer devices which regulate boiler operating temperature in conjunction with outside ambient air temperature.

The use of a solar flat plate collector system in conjunction with such a computer controlled baseboard hot water system is tested for various system strategies using a computer simulation. The simulation uses actual weather data collected at Kings Point, N. Y. in 1977 and provides a minute by minute analysis of each strategy tested. Figure 1 shows one such strategy.

In this system four small water storage tanks (180 Kg) are used instead of one large one. The tanks are placed in series with the boiler and are heated from the solar collectors by means of heat exchangers inside the storage tanks. The amount of energy provided to each tank by the solar collectors is found from the Hottel-Whillier equation using the well known methods of Duffie and Beckman. The tank and boiler temperatures for each minute are found using the method of Euler Integration and the "on" time of the boiler is determined by the heating load requirements of the house. The energy savings provided by solar is determined by comparing the energy that would have to be provided by the boiler if no solar supplement were present to the energy provided by the boiler in conjunction with solar.

In Figure 2 the storage tanks are in parallel with the boiler. Heating is provided by the storage tanks as long as their temperature is above some critical temperature. Otherwise heating is provided by the boiler, independent of the tanks.

The testing of various system strategies showed that the use of a computer control to regulate boiler operating temperature can give a significant increase in the fraction of energy supplied by the solar supplement. It was also found that the parallel strategy gives slightly better results than the series strategy and that the use of several smaller storage tanks in place of one large one has little effect on the over-all results.

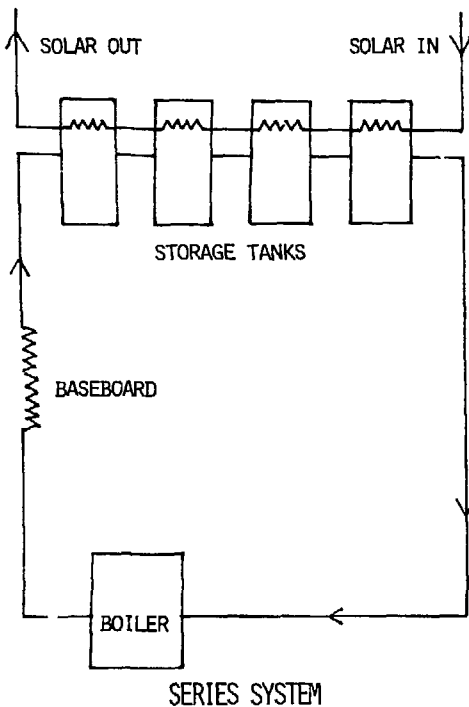


Figure 1.

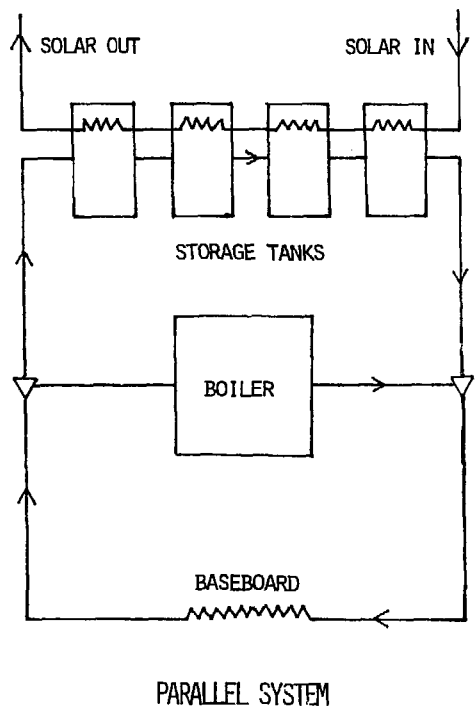


Figure 2.

Use of Solar Energy for Space Heating and Cooling in
Kitami District.

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ABSTRACT

For the purpose of practical use of solar energy on the area of heat engineering, the measurement of insolation at Kitami Institute of Technology was started twelve years ago, and then the experiments on space heating of a drawing room using solar energy were followed by equipping the full-scale facilities on a part of our Institute building. Since then four seasons of winter were already passed in 1980. The expected results on the experiment were obtained by improving the equipments and facilities every year. On the other hand the experiment of space cooling for the drawing room in our Institute was performed for about one month in the summer, 1979, introducing an absorption refrigerator into our solar system. In addition to the old solar collector for space heating and hot water supply, a new solar collector was installed at slightly inclined elevation angle of 25 deg. On the day of which maximum temperature was over 30°C, the experiment of space cooling was done, and the data were summerized.

Radiative Cooling and Solar Heating Potential by Using an Integrated Radiator/Collector/Roof Module

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Abstract

Several prototypes of a radiator/collector/roof module are being designed, constructed and tested for thermal performance in order to develop multi-purpose roof elements. The radiator/collector/roof will collect solar energy for space heating during winter days and provide cooling by radiating heat to the sky during summer nights in arid climates. About 70% of the heating and cooling demand could be provided in a house located in an arid climate by using such an integrated radiator/collector/roof. Radiative cooling is the effect of heat loss by a body due to long wavelength radiation to the night sky, and occurs in arid climates such as the Southwest of the United States and certain regions of Asia, Africa, South American and Europe. Experiments have shown this heat loss amounts to about 30 Btu/hr ft² with the surface temperature of a tested module near ambient. Typically, radiator/collector modules of low-cost galvanized metal sheets could also serve as the roof of a building. Traditional roofing materials such as asphalt shingles, galvanized steel panels etc. are undergoing the so called zero efficiency test at New Mexico State University to select the most promising samples for further study on radiation/collector/roof modules. This test is a means of assessing the radiation heat transfer effectiveness of a surface, and does so by simultaneously measuring the sky, ambient air and radiating surface temperatures. The heat transfer effectiveness of the most promising materials is being enhanced by applying specially chosen paints and selective coatings. In the next stage the best material is selected for the construction of the full size radiator/collector/roof modules of 4 feet by 8 feet. Module configurations for both air and water or water/antifreeze solutions as the heat transfer fluid are being studied. Each of the modules is also subjected to thermal performance testing in the solar collection made in accordance with the ASHRAE Standard 93-77, "Methods of Testing to Determine the Thermal Performance of Solar Collectors". The best modules from the point of view of thermal efficiency, cost, availability of materials and compatibility with standard construction methods according to the building code are being recommended to the state for consideration by the building construction industry.

SIMULATION OF SOLAR-SYSTEMS
USING A GENERAL PURPOSE MINICOMPUTER

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Abstract

In solving the problem of simulation for solar-thermal installations we were able not only to investigate the effect of construction parameters of solar-installations on the energy output (like collector area, storage volume, and so on), but also to provide the possibility for quantifying the influence of the control parameters of the solar systems. The simulation may be controlled interactively and the progress of simulation can be visualized or can be recorded for detailed offline evaluations. Special problems and advantages are emphasized if such a complex system is modelled within the limits of a general purpose mini-computer system.

A DESIGN OF A SOLAR DESERT COOLER FOR USE IN ARID CLIMATES

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Abstract

The paper deals with a design of a complete desert cooler for areas with dry climate. It is a chimney design with a tent-like base. The tent is a flat plate collector made of copper segments and selectively coated with copper oxide with one glass cover. The wind speed coming out of the chimney was 50 km/hr and above. The chimney was designed to accomodate a finned-rotor which was in turn coupled to the desert cooler rotor. Friction was minimized by using high quality ball-bearings. At the first stage of this research a drip type technique was employed to the pads of the desert cooler while effective steps were taken to have an integrated pump in the system. Measurements of temperature, radiation, relative humidity and efficiencis at various times of day were taken and the economics of such an invention is being assessed. A simple stainless steel concentrator was also used to increase the temperature of the collector and hence increase the wind speed through the chimney.

THEORETICAL COMPARISON BETWEEN IDEAL SINGLE,
DUAL AND MULTISTAGE ABSORPTION CYCLES

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Abstract

The absorption system may be considered as one of the most suitable systems for solar air conditioning applications. In the literature there is an intensive study about the single stage cycle, because it requires heat at low generator temperature. This low generator temperature may be supplied with heat from normal flat plate collector. The COP in this case is quite low.

To increase the coefficient of performance (COP) of the system a multistage cycle may be used. COP may be doubled when a two stage cycle is used in comparison to that of single cycle. Such cycle requires higher generator temperature which reduces the collector efficiency. These collector losses for a two glass cover plates overrides the improvement in the COP. Using the new developed evacuated tubular collector this disadvantage may be eliminated. A computer program has been developed to compare between a single stage flat plate collector and a two stage evacuated tube collector for one typical summer day load. In arid zones where water is rare the dual cycle may be considered as one possible solution, since it requires no cooling tower. Comparison has been made between this dual cycle system with other systems according to the availability and consequently the cooling tower water consumption cost must be considered. A new defined water-collector cost ratio is introduced.

A COMPUTER PACKAGE FOR THE DESIGN AND OPTIMIZATION OF AN
ABSORPTION AIR CONDITIONING SYSTEM OPERATED BY SOLAR ENERGY

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Abstract

A general study on design and optimisation of the new dual cycle 1,2,3 has been undertaken. The simple water Lithium bromide and ammonia-water refrigerant-absorber combinations were also chosen for this study because of their extensive use in absorption refrigeration and air conditioning systems 4,5,6,7 especially those operated by solar energy.

The dual system is very much appropriate for places where the solar energy is available and where the water is pure and consequently the cooling tower may be eliminated.

A simulation model capable of estimating the long-term thermal performance of the solar air conditioning system is described.

A computer model of the solar energy system was developed. A comparison of the three cycles indicates that the water-lithium bromide system is better and simpler than the ammonia-water system. In design and optimisation of the performance of an absorption system the most important variable, which has to be taken into account, is the temperature of the generator.

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PERFORMANCE OF MULTIPLE WICK EVAPORATIVE COOLING
SYSTEM

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ABSTRACT

This communication presents the design, analysis and performance of a multiple wick evaporating cooling system in which wet jute cloth forms the liquid surface. The wet surface is comprised of a series of jute cloth pieces of increasing width separated by thin polythene sheets, resting on the roof. These pieces are arranged like a tilted roof structure whose upper edge is dipped in a water tank. Suction by capillary action of the cloth fibre provides a thin sheet of liquied, the arrangement ensures that all the surface, irradiated by the sun is wet at all the times. Calculations show that on a typical summer day in Delhi, the heat flux coming into the room gets extremely reduced. The initial and maintainance cost of the system is also very small and no power is required to maintain the water film.

A SOLAR POWERED DESICCANT AIR CONDITIONING SYSTEM

by

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The high humidity and temperatures of the summer months are generally associated with sunny days. It is this natural occurrence which makes solar energy the logical energy source to power air conditioning systems. This paper discusses some of the steps taken to date by the Center for the Environment and Man, Inc. (CEM) in the design and development of a solar powered desiccant air conditioning system using silica gel. The system operates on a dehumidification/rehumidification cycle and can function as both an air conditioner and a dehumidifier. CEM established a preliminary design for a two-ton residential unit and constructed and tested a 1/4 capacity test model and demonstration unit. The air conditioning system is designed to operate at temperatures attainable with medium temperature, flat plate solar collectors.

CEM developed a mathematical model which accurately defined the adsorption and desorption of water vapor on silica gel as its main analytical tool. The model, validated with available experimental data, evaluated many different parameters which enabled prediction of silica gel bed performance over a wide range of conditions. Using these results, the bed-size and air flow rates for desiccation/rehumidification air conditioning were optimized for given adsorption and desorption conditions.

The 1/4 capacity test bed is split into adsorption and desorption sides and incorporates a rotating silica gel bed. The rotating bed approach permits reuse of the silica gel while always providing fresh, dry desiccant to the absorption side of the unit. As the bed rotates slowly, the bed residence time in either side can be varied to attain optimum adsorption or desorption of the silica gel.

Sealing of the air flow paths has proven to be a difficult task. The adsorption and desorption sides must be isolated from each other to prevent cross-flow. Similarly, the rotating bed must be well sealed to prevent any blow-by. Air leakage between stages in the rotating bed and between the two sides have combined to reduce the efficacy of the 1/4 capacity unit.

The test facility simulates the energy obtained from a solar collection system and does not include the rehumidification step in the air conditioning system process. Tests were conducted to validate the moisture removal efficiency of the system design. Under optimum adsorption/desorption residence times of twenty (20) minutes each, the tests to date

show below-prediction moisture removal rates. Due to the sealing problems described earlier, only 55% of the available moisture was removed from the air flow. This value is only slightly over 60% of the predicted removal rate for the twenty minute cycle.

It is believed that the moisture removal efficiency rate can be easily increased by correcting the air flow problems of the prototype test system. Two methods appear reasonable: One calls for improved sealing methods applied to the same rotating bed concept. The second method would employ a fixed bed configuration. The fixed bed would require the air flows to be alternated between sides at the end of each adsorption/desorption cycle. The overall effectiveness of the system may suffer from these periodic interruptions in air flow.

As the underdeveloped countries of the world develop higher standards of living, solar energy for air conditioning will become more meaningful since many of the countries lie in the equatorial zones.

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SESSION 3B

SOLAR APPLICATIONS I

INTEGRATED ENERGY SYSTEM CENTERED AROUND
AN ANIMAL SCIENCES FARM

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EXTENDED ABSTRACT

INTRODUCTION

New Mexico State University has proposed to build a \$2.5 million demonstration facility centered about an animal sciences farm. The farm would have a 200-head dairy herd, 500 sheep, 250 hogs, and 50-250 beef cattle. Besides producing milk, meat, and wool, the farm would process the animal wastes to make methane for electrical generation and to grow algae or other high-protein feed.

PLOT PLAN

The facilities would be arranged so that the wastes could be flushed with water into an anaerobic digester. A plan showing the layout of the farm is presented in figure 1. Because the farm would be located on land which

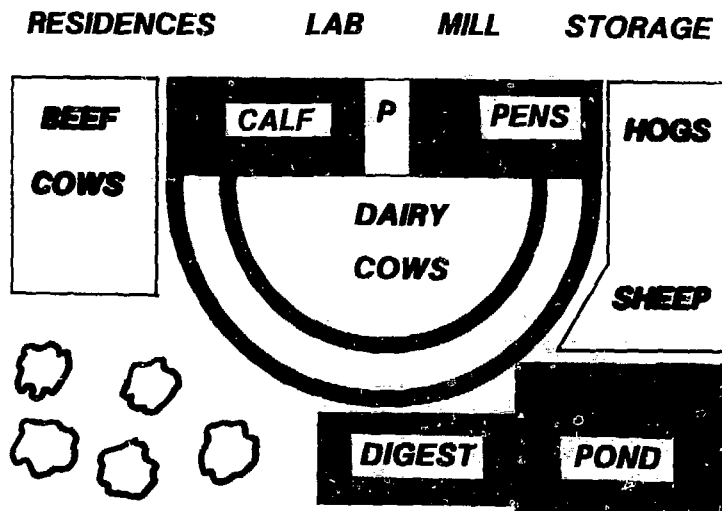


FIGURE 1 PLOT PLAN

slopes downward to the south, wastes would flow by gravity, thereby minimizing pumping costs. The arrangement would minimize the cost of handling feed, yet would facilitate animal care. The buildings would be solar heated.

ENERGY SYSTEM

A process flowsheet for the waste treatment portion of the system is presented in figure 2. During the first step, the wastes would be digested anaerobically to produce methane. The methane would be scrubbed with water to remove carbon dioxide, then sent to the electrical generators and boilers. Daily methane production would be about 9 to 17 thousand SCF on a dry, CO₂-free basis.

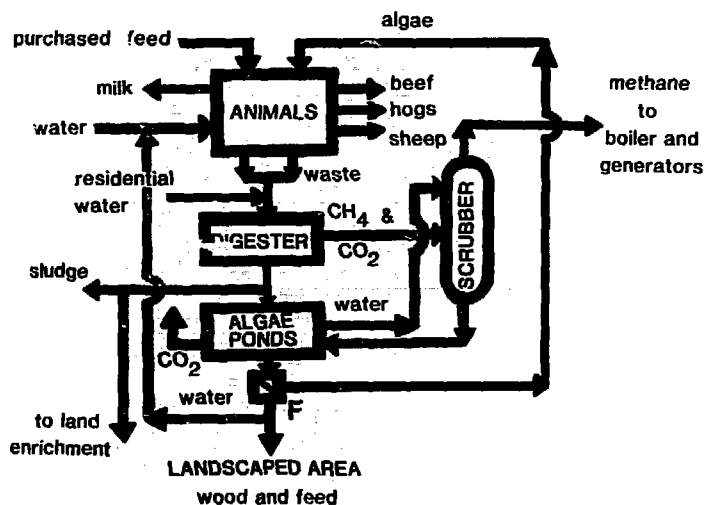


FIG 2 ENERGY FLOWCHART

Some of the sludge from the digester may be dewatered and incorporated into beef cattle rations, spread on the landscaped area, or used for earthworm production. Most, however, will flow to algae ponds where it will be consumed. The algae will be harvested and processed to cattle feed. The algae will purify the water sufficiently enough so that it may be recycled to the animal unit and used for flushing the wastes. Excess water will be used on crops surrounding the farm.

Energy would be produced from the methane as shown schematically in figure 3. Some of it will be used to raise steam needed by the feed mill. Most will be used to power electrical generators (G). Methane production would be sufficient to provide all the electricity and steam needed by the

facilities. Daily energy requirements are estimated to be 8.64 GJ to run an electrical generator and 3.68 GJ for steam. The energy available from biogas would be 10 to 18 GJ per day. Water heating would require 1.3 GJ of additional energy, but this would be derived from the waste heat leaving the generator engines.

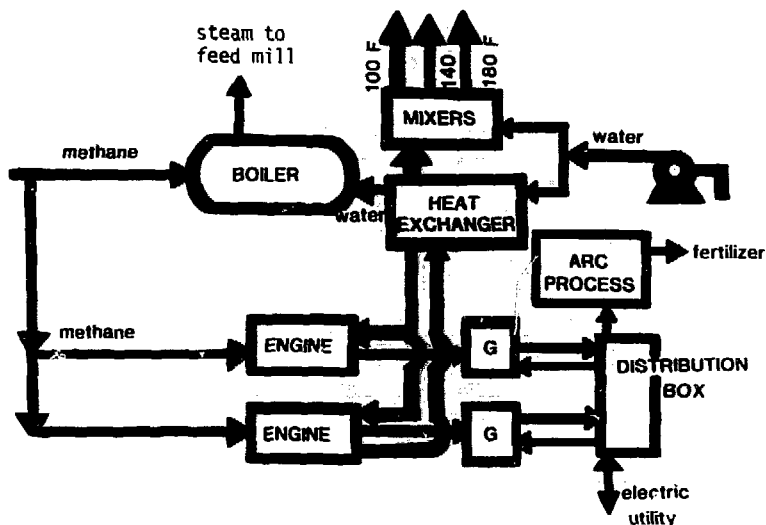


FIG 3 ENERGY FLOWCHART

Because methane and hence electricity will be produced continuously, electric power would often be in excess. This power may be used to produce fertilizer by fixation of atmospheric nitrogen in an electric arc. During periods when electricity demand exceeds the generator's capacity, power will be taken from a utility company's grid.

DIGESTER DESIGN

The anaerobic digesters proposed for this farm are of a low-cost design developed at the New Mexico Solar Energy Institute. They are essentially bags made of rubberized fabric that can operate for 20 years without repairs. They will rest in depressions in the earth; no special foundations or supports are needed.

INTEGRATED RENEWABLE ENERGY SYSTEMS IN AGRICULTURE - AN EXAMPLE OF APPLICATION

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The research aims at analysing the technical feasibility and economic significance of the use of a mutually integrated, renewable energy system, finalised to meet the farm's energy requirements.

Among the possible energy sources, the system assumed is based on solar energy and byproduct combustion. This because, such energies may be considered, at least in Europe, the most immediately applicable, as they are backed by mature technologies.

The energy demand profile and the available renewable energy sources are established; then the possible utilization of the energies is analysed on the basis of the electricity and heat needs of the farm.

The different technical solutions are determined and an optimization model is developed. Afterwards, the dimensions of the individual components are established so as to define a solution which will minimise the cost of the produced energy.

This model makes it possible to assess the economic incidence of the various possible solutions and the unit costs of renewable energy, in the framework of a closed "input/output" system, as represented by the farm.

CONTRIBUTION OF ALTERNATIVE ENERGIES TO MEET THE NEEDS OF RURAL AREAS

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EXTENDED ABSTRACT

INTRODUCTION AND SCOPE OF THE WORK

The present work is being performed under the sponsorship and the cooperation of the Piedmont (Italy) Region Government. It involves also researches in fields other than the analysis of the alternative energy resources with which we are concerned in this paper, such as building energy savings and district heating in large urban areas.

To achieve a general overview of the local energy situation, a detailed investigation of the region energy system, of which agriculture is a part, is carried on, trying to collect and organize all the available informations, to have an as good as possible picture of the situation that must be faced.

The result should be the implantation of an energy related and finalized data bank for the region. Such an effort is mainly intended to give a means for a correct planning of the whole system, for which, in our opinion, in the present day situation, due attention should be paid to the "energy parameter".

DESCRIPTION OF THE WORK

An energy balance of the agricultural system is attempted, in the framework of other similar analyses [1], at least at a first degree of approximation.

The agricultural system is regarded as both an energy utilizer and an actual energy producer, through its outputs, such as the ones which enter the human alimentary chain, as well as a potential energy producer [2] through wastes and biomasses, such as manure, straw and other subproducts which at the moment are not, or not fully, utilized and through specifically energetic resources, such as a large portion of the forestry resources.

The data upon the agricultural productions and the invested surfaces are collected and interpreted, keeping in mind their historical evolution.

It is strongly felt that a work mainly directed to obtain better and more up to date information is necessary: such a work, however, goes far beyond the scope of the present study. Some typical areas and crops which seem to be quite significant, namely wheat, corn and rice together with animal breeding are more deeply investigated.

Such an analysis enlightens the energy needs of rural areas, the form of its use and the sources at present employed.

Aftwards, we discuss the specific sector within the rural system where alternative energy resources, some of which output by agriculture itself could give a significant contribution, in substitution to conventional and fossil non renewable sources, special attention being devoted to the low temperature needs, namely for large scale livestock plants, crop drying and greenhouses, where solar but specially biomass energies, either directly or through anaerobic fermentation to yield biogas seem to deserve a special investigation.

In this last field an improvement of the technological and engineering knowledge would be highly welcome, and in this respect parallel studies are carried on [3].

The utilization of part of the biomass energy produced in agriculture, specially burning wood and biogas, in fields other than agriculture itself in rural or close by areas could be important [4].

The total potentialities are calculated and a first step towards a cost analysis, though difficult at the present stage of the technological and commercial situation of the field, and the implications of an alternative energy exploitation planning decision is begun. The analysis of the global benefit should not be isolated and only the absolute values put into evidence, but the interacting aspects should be taken into account, such as pollution and agronomy, and it is in this respect that perspectives look favourable.

The anaerobic digestion for biogas production from animal manures, for instance, is altogether a purification technique which reduces the ecological impact of the liquid discharges of the plants and the solid organic matter can fruitfully be used as a fertilizer, in such a way bringing precious nitrogen to the crops, improving yields and preserving the quality of the agricultural land.

PRELIMINARY CONCLUSIONS

The present work stands as an attempt to investigate both the potentialities and the implications of an exploitation of alternative energies in the agricultural field and the possible biomass energy output in a region in the Northern part of Italy. From the preliminary results it may be

concluded that such resources are quite important for the optimization and the correct management and development of rural areas.

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Abstract

WARM AIR POULTRY BROODING SYSTEM
UTILIZING A DIRECT COMBUSTION WOOD FURNACE

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As the energy crisis escalated during the mid-1970's, it was recognized that a significant portion of America's total energy consumption was used by the poultry industry. Georgia Tech conceived an alternate fuel system that would be applicable both to new and existing installations. Construction of such a system was begun as a demonstration project in mid-1977 and completed in mid-1978. Since that time, the system has been functional and has demonstrated a high degree of reliability as well as affecting considerable cost savings.

The site selected was on a farm in Western Georgia. The farm had two identical grow-out houses in close proximity to each other with the same orientation with regard to sun and prevailing winds. The houses were of the side-curtain variety, 325 feet long by 35 feet wide, and would normally house 13,000 to 17,000 broilers per house. The ceilings were insulated but no insulation was provided in the sidewalls of the house. Each house contained 5 ventilation fans and 20 propane brooders rated at 30,000 Btu's per unit.

The system consists of 3 main components--a woodburning furnace, a main supply, distribution and return duct, and 20 flexible ducts which simulate the function of the propane brooders by providing warm air close to the ground. A separate structure was provided to house the furnace and wood supply with the furnace house being located at the mid-point of the grow-out house to allow symmetrical and naturally balanced air distribution. Exposed ducting from the furnace house to the grow-out houses was insulated and weather-proofed to reduce potential heat losses that could occur during inclement weather conditions. Following the inclined roof line to the ceiling, the duct branches out into two long runs down the length of the house. Flexible 8" diameter ducts are located at approximately 15' intervals to supply warm air to ground level. The air is then distributed parallel to the ground by means of slightly oversized concentric ceiling diffusers. Since the poultry company to which the grower is under contract utilizes partial house brooding, a damper was installed to block off either half of the house

as necessary. Consequently, both sides of the systems were sized generously to accommodate an increased air flow. This also allows complete symmetry and natural balancing for ease of installation and operation.

The first flock of birds to be brooded with the warm air system arrived at the farm in October of 1978. The propane brooders were left in place as a precaution until the reliability of the new system was proved. This was accomplished with this first flock and the brooders have been stored out of the way for the past two heating seasons with two exceptions. These two times were again precautionary measures, as there was a combination of very cold weather and very young birds.

The wood usage has averaged approximately 30 cords per year for the two seasons and propane usage has averaged 3800 gallons per year. In this area of Georgia, the cost of fuelwood has remained stable over the two-year period, whereas the price of propane has continually increased. Thus, the grower has the additional benefit of increasing cost savings while utilizing a renewable resource as fuel.

NATURAL/PASSIVE SOLAR HEATING AND COOLING FOR
POULTRY SHEDS

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EXTENDED ABSTRACT

Arid climates, as in Egypt and the Middle-East regions, are characterized by large diurnal and seasonal temperature variation coupled with clear skies and ample sunshine duration. Partial stabilization of indoor thermal environment in habitation is of great comfort for human and have large effects on animals or birds productivities.

Active solar energy systems for this purpose are not quite feasible according to energy, economical costs and cannot generally apply in our developing country. In case of poultry or animal sheds, can have some economical turn over in terms of increased egg or animal productivity and reduction of mortality rates if their indoor thermal environment is favorably controlled. Poultry birds are sensitive to changes of ambient temperatures, humidity and other environmental variables. The ranges of these variables for efficient operation are well established in terms of bird's diet, breed and body weight.

This investigation describes an unconventional method of maintaining moderate thermal environment within poultry sheds by using the roof for storage of heat and coolness in appropriate seasons.

During winter, underground water (26°C at 5 meters deep) is circulated through specially designed pipe matrix imbedded in the roof slab and through radiant wall panels. The pipe matrix replaces the standard steel reinforcement for the roof. This underground water heats the roof and the panels for radiant heating of the shed.

During summer, water in the roof pond (15 cm deep) is cooled due to night sky radiation and natural evaporation. This cooled water is circulated through the same pipe matrix and wall panels to store coolness.

In order to supply the necessary heat at all time for an experimental hatchery space, a Thomson's roof pond solar collector, underground well insulated storage system and

wall radiant panels were designed. Water is used as the medium as it ensures uniformity of temperature by natural mixing both when heating or cooling. The constructions are designed taking into consideration the factors which influence the thermal performance such as its heat capacity, type of materials used for its construction, orientation and ventilation openings.

This paper involves examining and testing the basic data for the construction of a simple moderate cost poultry shed. These data were:

- 1-Testing of several types of building materials for strength, optical properties as well as weather durability, with the emphasis on local readily available materials.
- 2-Cost estimates of the construction of an actual experimental poultry shed.
- 3-Computations of the thermal design procedure to predict the indoor thermal conditions- both mean values and diurnal variation- using a response factor method.
- 4- Cost analysis of such shed and comparison with conventional ones were made.

PASSIVE SOLAR HEN HOUSE - SECOND YEAR

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ABSTRACT

This paper describes the second year's study of a solar hen house. The first year's study demonstrated that a small flock of hens living in a solar environment can produce more eggs at a greater feed efficiency than that predicted by the U.S. Department of Agriculture (USDA) projections for hens housed in standard hen housing. For this second year's work a new flock of hens was divided into 2 groups - one housed in the solar hen house, the other in a barn. The results of egg production and feed consumption were monitored continuously and compared to each other. In addition, these results were compared to a standard large commercial operation and a 10 year university egg production study. The solar hen house is 8 feet by 8 feet with a 45 degree double-glass south facing surface. No electricity, gas or oil is used. The ventilation is a wind driven ventilator with a manually controlled damper; the footing is insulated with 2 inches of polystyrene and is 2 feet deep. The storage medium is 2295 pounds of water stored in 55 gallon drums. The hen house is solidly built and well insulated; all the glass surfaces are double glass.

The 11 hens are Rhode Island Reds that were barn raised for 29 weeks. They were then split into two groups with 6 hens going to the solar hen house and 5 remaining in the barn. The barn provides an inside area of 66 square feet and has an insulated nesting area that receives natural south light from a skylight. The barn has an outside run of 240 square feet or about 48 square feet per hen while the solar greenhouse run is 100 square feet or about 16 square feet per hen.

The litter is controlled by the daily removal of sawdust and manure that accumulates on the top of the nests where the chickens roost. Clean sawdust is then applied in preparation for the following night. About 1500 pounds of manure and sawdust is cycled into the garden yearly by way of the compost pile.

*All work performed at author's home.

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The production rates are proving higher than predicted both in the solar hen house and the barn. The reasons for this are explored from the point of view of a comparison with the usual commercial operation - housing area per hen, natural light vs. artificial light, hours of lighting, ambient temperatures, humidity and feed. In addition the higher production rates are looked at with a comparison of the amount of earth access per hen.

SOLAR WATER PUMPING FOR REMOTE RURAL AREAS

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EXTENDED ABSTRACT

INTRODUCTION

A large portion of the world population lives in remote villages where water supply is most important for their development. There are several energy alternatives for water pumping in these areas, but the photothermal solar energy conversion through a Rankine cycle using flat plate collectors is contemplated in this work.

Although the thermodynamic availability of solar energy at these collector temperature levels is relatively low [1], the entire system has to be almost maintenance free and of an appropriate technology level for these rural applications where the small villages are remote from roads and main electric or fuel distribution networks. On the other hand, the advantages of using flat plate collectors in these applications are threefold:

(1) They accept direct and diffuse radiation. This factor may be very important in those areas where the diffuse component of solar radiation is large.

(2) Flat plate collectors do not have some of the disadvantages of focusing collectors; namely, a continuous tracking of the sun motion and a more sophisticated technology level in the manufacturing process. Furthermore, it is recognized that black chrome selective surfaces do not sustain working temperatures above 250-300 °C without an irreversible degradation.

(3) Flat plate collectors can be an integral part of the roof building. Therefore, a dwelling for the village needs hospital, school, etc.- can be built as a part of the installation.

Several studies indicate that the pumping unit can be designed according to the following approximate daily water

consumption figures: 50 liters/person, 40 liters/head of livestock, and $60\text{--}150 \text{ m}^3/10^4 \text{ m}^2$ of irrigated land. Of course, these figures vary from country to country and from site to site. On the other hand, the collector area -which is the most important part of the pumping unit- should be determined according to the local insolation values. The type of working fluid in the Rankine cycle should be also considered taking into account its physical properties.

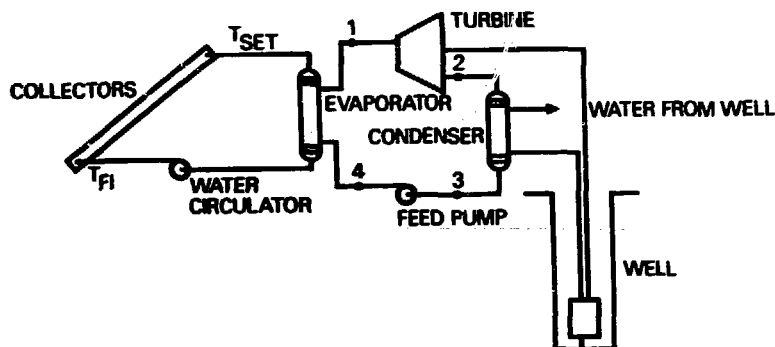


Fig. 1. A Typical Rankine Cycle.

MATHEMATICAL MODEL

A mathematical model to describe the thermal performance of a collector field and a Rankine cycle using Freon 11 or Freon 114 is presented in this paper. Figure 1 shows the solar pump under consideration. The physical behavior of the working fluid within the cycle is described by an equation of state based on the three-parameter corresponding states principle developed by Lee and Kesler [2].

On the other hand, the collector field thermal performance is predicted by resorting only to monthly average daily values of radiation [3].

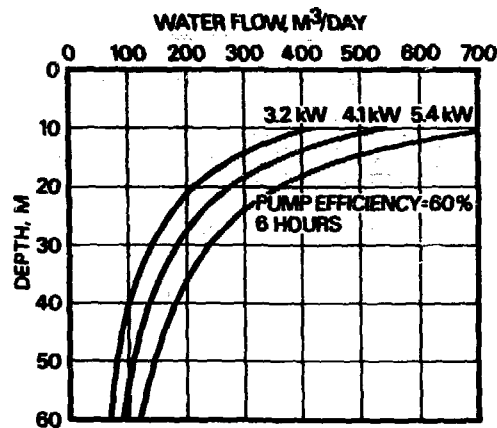


Fig. 2. Water Volume as a Function of Well Depth.

As an illustration of the model results, Figure 2 depicts the variation of the daily water volume obtained during six hours of operation for different well depths. It is observed that, for a given power output, the amount of water increases as the well depth decreases.

CONCLUDING REMARKS

The model under consideration may be used in the design or selection of a solar pumping unit. Furthermore, the model may be used to determine those areas where further research development has to be carried out to improve performance.

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PREHEATED DOUBLE EXPOSURE SOLAR WATER DISTILLER

I. CONSTRUCTION AND THEORETICAL ANALYSES

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II. EXPERIMENTAL RESULTS

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Part I. ABSTRACT

A modified type for the double exposure solar water distiller (*) is introduced by preheating the saline water before entering the still by a flat plate collector as shown in photograph.

The construction and the theoretical prediction were carried out by optical and thermal analyses. These investigations involve both optimum shape which capture maximum solar radiation and optimum inlet temperature to the double exposure still for the maximum productivity.

Energy balance is also investigated for both the flat plate collector and the still used.

*" Double exposure Solar Water Distiller, " I..A. Sakr, M. Zahran, M. Abd Rabbo & H. Moussa, International Workshop on Solar Gas Heating, Perpignac, France, Dec. 1979.

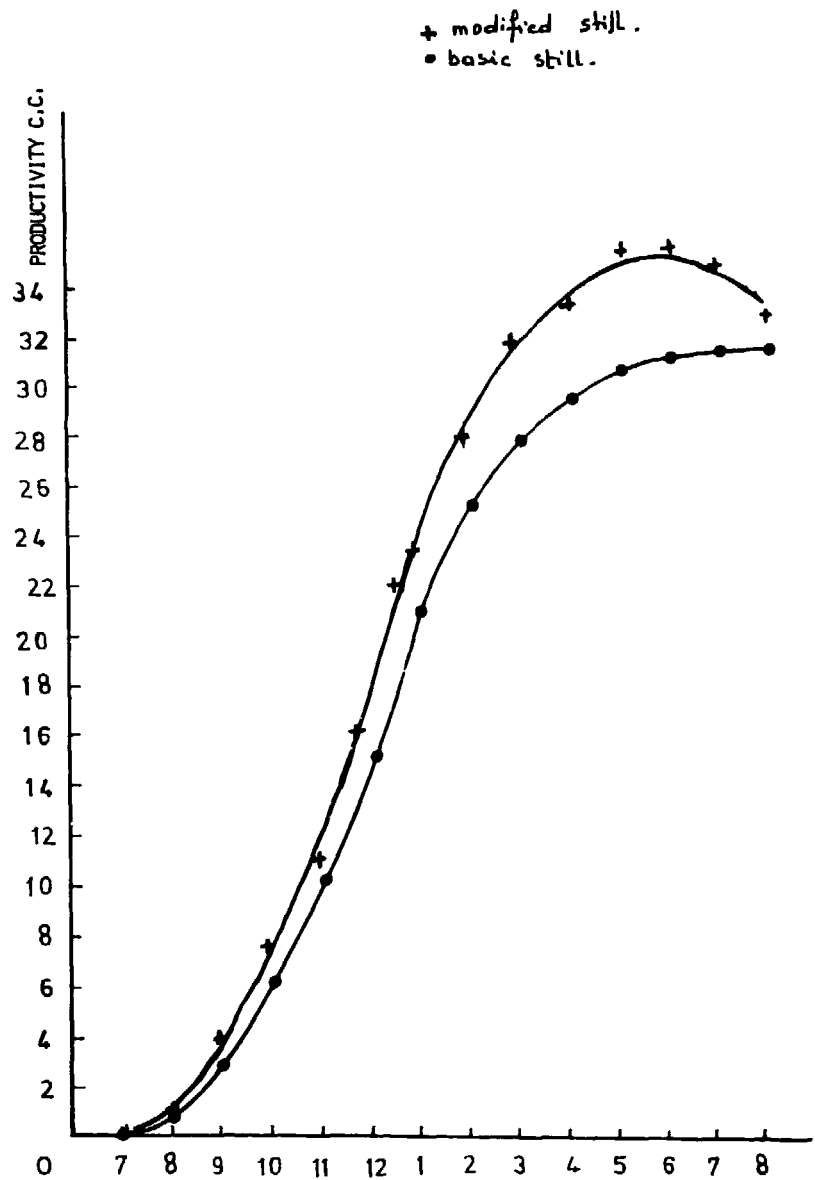


FIG. 1 AVERAGE PRODUCTIVITY FOR 1100 STILL OVER FIVE DAYS

Part II. ABSTRACT

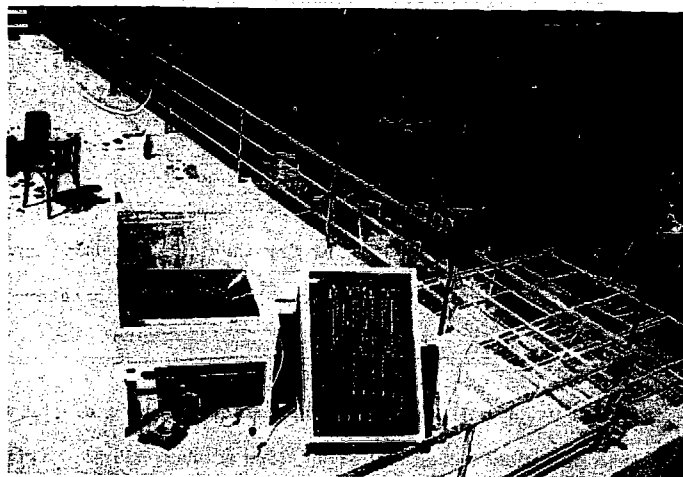
A prototype of the still unit described in the previous paper which was constructed by the help of optical and thermal investigations was tested. Tests were carried out in August 1979 at the Faculty of Engineering, Shoubra, Cairo ($30^{\circ} 2' N$, $31^{\circ} 2' E$).

Results show maximum average productivity at front mirror angle 110° and an improvement in productivity of about 17% over the basic type as shown in figure.

The effect of mirror angles on still performance showed that the specific yield of the modified still is higher than the standard type. This is due to the preheating of the saline water in the evaporator using a flat plate collector.

The condensed water collected from the different sides of the still comes mainly from the glass cover and front face mirror. Productivity was further increased by 26% when part of the water vapour is allowed to be condensed externally of the system using a heat exchanger.

The variation of the Basin temperatures, the vapour temperature and the feed water temperatures were recorded and plotted for both the modified and the standard systems.



A THEORETICAL STUDY OF HEAT AND MASS TRANSFER PROCESSES IN HORIZONTAL-PLANE AND INCLINED STEPPED SOLAR STILLs

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EXTENDED ABSTRACT

INTRODUCTION

Solar stills are used for production of potable water from brine or from salty water available in rural areas. Different types of solar stills have come into existence. These stills are broadly classified into a) horizontal or convective hot-box type b) inclined stepped type. The heat and mass transfer characteristics do vary between these two types of solar stills. The main aim of this paper is to develop heat transfer equations involved in the above stills and also to study mass transfer characteristics.

HOT-BOX TYPE SOLAR STILLs:

It is well established that the local Nusselt number, Nu_x is a function of Prandtl and Grashof number, i.e., $Nu_x = f(Gr_x, Pr)$ for the above still. It is experimentally proved that

$$Nu_x = 0.379(Gr_x)^{0.25}$$

for the vapour Prandtl number approaching unity. But in practical cases pure natural or forced convection do not take place in convective solar stills. The heat transfer takes place by mixed convection when the vapour diffuses into vapour-air mixture. Hence the Grashof number used in the above equations should be modified into to take into account the density gradients which exist between vapour surface and vapour-air mixture. It is also shown in this paper that the Nusselt number is also a function of a new parameter which is the same as the dimensionless superheat involved in boiling cases. The superheat given here is of the form $C_p T/h_{fg} Pr_v$. Hence,

$$Nu_x = f(Re, Gr', SP)$$

The Reynolds number is calculated from

$$Re = G_l / \mu_m v_m$$

The Nusselt number is also defined in the usual form as,

$$Nu_x = h_l / k$$

where the heat transfer coefficient h is given by

$$h = \dot{m} h_{fg} / \Delta A T$$

Thus a new attempt is being approached to analyse the problem in the form of a mixed convection evaporation from the surface of the brine.

INCLINED STEPPED SOLAR STILLs:

It is well established that the evaporation rate from the inclined stepped stills have higher output [1] Viz, 30 to 40 Percent more than the hot bed type. In this the heat transfer coefficient depends on the height and number of steps in the stills. The height of the steps is calculated from

$$h = (l/n-t) \tan \alpha.$$

Equations are also derived to calculate the optimum number of steps, in terms of shadow areas, inclination of the sun's rays, orientation etc.

CONCLUSIONS :

- 1) The heat transfer and hence the evaporation rate is higher for stepped Solar Stills than horizontal stills.
- 2) The Nusselt number is a function of Reynolds number, a modified Grashof number and dimensionless superheat.
3. The heat transfer is largely affected by the formation of horizontal and vertical shadows which depend on orientation of the still, angle of incidence of solar rays, and the distance between the working and transparent surfaces.

NOMENCLATURE:

A	- Area of Still
Gr	- Grashof number, $g\beta\Delta T l^3/\nu^2$
Gr*	- Modified Grashof number
h_{fg}	- Latent heat of vapourisation
k	- Thermal conductivity
l	- Length of Solar Still
m	- Mass flow of vapour
n	- Number of steps
SP	- Dimensionless Superheat
t	- Thickness of step
v_m	- Mean velocity of vapour-air mixture
ΔT	- Temperature difference between the evaporation surface and condensation surface
ρ_m	- Density
α	- Inclination of still

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TRANSIENT THEORY OF SINGLE AS WELL
AS DOUBLE STAGE SOLAR STILLs

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ABSTRACT

The phenomenal increase in cost of energy has triggered renewed interest in conventional solar stills. This paper presents transient analytical model to evaluate the performance of single as well as double stage solar stills; the latter type in effect is two single stage solar stills kept one above the other. The experimental observations are found to be in good agreement with the theoretical predictions. The model can be used to predict the performance of these type of stills with reference to abroad range of climatological variables.

LOCALIZED STATES CAN ENHANCE
THE EFFICIENCY OF A SOLAR CELL

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EXTENDED ABSTRACT

Standard current solar cells are almost exclusively made of narrow energy gap (less than 1.45 eV) materials and great care is taken in their fabrication to avoid localized states within the energy gap [1]. However, localized states within the band gap of a semiconductor can enhance the efficiency of a solar cell provided that generation of electronhole pairs by photons via the localized states predominates over recombination through these same states. By utilizing such states the useful range of energy gaps in solar cells can be extended to 4.0 electric volts and better.

The following subjects required to design a solar cell utilizing localized states are reviewed: (1) radiative and nonradiative transitions in semiconductors with localized states [2], (2) photon absorption in a semiconductor with localized states, (3) charge carrier density in a uniformly illuminated solar cell and (4) saturation current density of nonilluminated solar cells. Having reviewed the device physics this paper considers two examples of localized solar cell design: one with radiative transitions only and a second design including the effects of both radiative and nonradiative transitions. Using side illuminated (vertical) solar cells and wide gap (2.8-3.7 eV) semiconductors efficiencies of 26.34% are predicted for cases in which radiative transitions predominate as opposed to predicted efficiencies for standard cells (no localized states within the energy gap) of these energy gaps of 24% [3]. Solar cells with predominately nonradiative transitions exhibit a predicted efficiency of 14% for an energy gap of 3.7 eV. This is a significant improvement over the 2% value predicted for conventional cells of this energy gap.

We conclude that it is possible to design high efficiency solar cells with localized states. However, the structures obtained in both examples designs are difficult to fabricate. Further, experimental research into materials and fabrication technologies will be required to develop a practical solar cell design of this type.

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'ON ELECTROCHEMICAL SOLAR CELLS'

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EXTENDED ABSTRACT

In the last few years photoelectrochemical systems have received great attention and gained in importance because of their attractive features for conversion of solar energy [1]. However, there is a long way to go, before, some serious problems associated with these systems are solved, such as instability or very low efficiency, and before an engineering design for electrochemical solar cell panels is worked out.

In spite of a very large number of investigations, carried out over a long period in the past, primarily by electrochemists, our understanding of the basic mechanisms in photoelectrochemical systems remains rather poor, and most electrochemical solar cells made so far are either unstable or the efficiency is very low.

The future investigations have therefore to be carried out both in theoretical as well as in experimental areas. In the case of theory, the least understood aspects are the charge transfer across semiconductor-electrolyte as well as metal-electrolyte interphases, the transport of charge across the bulk electrolyte, and the role of states on the semiconductor surface. In the theoretical part of the present work, a comprehensive but simplified picture of the photoelectrochemical system has been worked out. This theory includes the electrostatic analysis as well as analysis of the current-voltage characteristics. The above aspects have been considered in the analysis in addition to factors, such as, change of the interphase potential with the device voltage, which may be cause of the observed foot effect. An important feature of this theoretical analysis is the attempt made to present the theory in a manner and language, that are familiar to semiconductor device engineers, people who will have to be involved if these systems are ever to become commercially viable. To that end extensive use of energy level diagrams and equivalent circuit models have been developed. The light-generated current has been separately analyzed from the diode current. Also various erroneous assumptions and treatment frequently found in the literature have been pointed out.

The experimental work has been based mainly on the GaAs/K₂Se-K₂Se₂-KOH/Pt photoelectrochemical system. One aspect which has already been studied in detail by us is the effect of selenium pre-treatment of the GaAs surface as well as that of selenium followed by ruthenium pre-treatments. It has recently been reported that such pre-treatments of the GaAs surface greatly improve the performance, raising the conversion efficiency to about 12 percent, and also makes the cell stable [2]. Reason for this has not been established yet, although it has been suspected that the pre-treatments somehow affect the surface states. For the purpose of surface state determination, solid state MOS diodes were fabricated on three types of GaAs surfaces: (i) normally cleaned, (ii) normally cleaned and then selenium treated to remove arsenic from the surface, and (iii) normally cleaned, then selenium-treated, and followed by ruthenium-treatment. Capacitance-voltage and conductance-voltage measurements were taken to obtain the surface state distributions. Results indicate that, the selenium treatment is very effective in reducing the surface state density by removing arsenic from the surface. This increases the barrier height in GaAs and therefore the open-circuit voltage. The results also indicate that surface adsorption of ruthenium creates intermediate states, near the valence band edge, which aid the transfer of minority photocarriers, thereby increasing the fill factor and power output from the GaAs/K₂Se-K₂Se₂-KOH/Pt cell. Since photo-generated minority carriers now do not accumulate at the surface, the stability of the cell is also improved.

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COMBINED PHOTOVOLTAIC/THERMAL SYSTEM EXPERIMENT

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EXTENDED ABSTRACT

Most combined Photovoltaic/Thermal (PV/T) solar energy collection systems use a fluid (liquids such as water or gases such as air) as the heat transferring medium. In a gas system, both the lighted and dark side of the photovoltaic array can be in contact with the heat transfer medium, but to obtain good heat transfer characteristics with a gas, a significant amount of the energy collected must be used for pumping requirements. Up to now, in systems using a liquid heat transfer medium, the photovoltaic array is usually cooled by thermally bonding a fluid piping system on the dark side of the photovoltaic array. These design configurations characteristically result in the array operating at a significantly higher temperature than that of the heat transfer fluid. This higher relative operating temperature of the photovoltaic array reduces the electrical efficiency compared to that efficiency obtained if both operate at nearly the same temperature. The temperature difference between the photovoltaic and the heat transfer fluid also has the effect of lowering the thermal efficiency of the PV/T system.

In this experiment the possibility of using a liquid heat transfer medium in close contact with the entire photovoltaic surface is explored. The photovoltaic array is totally immersed in the liquid heat transfer fluid contained within the receiver module.

This design configuration improves the heat transfer characteristics of a combined PV/T system; the improved heat transfer characteristics can significantly improve both thermal and electrical efficiencies.

Although the immersion of a photovoltaic array in a fluid presents some problems, these problems are not insurmountable. The predominant problem is electrical losses due to absorption of solar energy by the heat transfer fluid on the lighted side of the photovoltaic surface combined with the short circuiting effect of an electrically conductive fluid.

This experiment is an attempt to solve these problems, and with proper design, the authors feel that this system can perform more efficiently than typical PV/T system designs.

A small-scale model receiver and concentrator was constructed and tested. This PV/T system model was tested as a flat-plate collector with no concentration and also as a receiver module at a low concentration ratio.

This paper will present the results of this experiment and a comparison to a straightforward analytical model with computer results for this type of PV/T system. This analysis is only meant to be an introduction to a possible evaluation of this type of PV/T system. Design criteria including economic factors and materials selection are discussed.

From the result of this experiment, many design possibilities are apparent. This paper will also present some suggested design changes based on the experimental results as well as areas of possible future research.

THERMAL CONVERSION IN THERMAL-PHOTOVOLTAIC SOLAR ENERGY SYSTEMS

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EXTENDED ABSTRACT

INTRODUCTION

Only a fraction of the solar spectrum can be transformed into electricity by a photovoltaic device, while most of the incoming energy is lost as heat. On the other hand, a high operating temperature in a photovoltaic system has a very strong adverse effect on its efficiency and this is particularly important in systems using concentrated solar radiation. Therefore, a photovoltaic installation must have an efficient cooling system which, properly designed, can also play the role of a thermal source to provide thermal energy when it is directly needed.

In a combined thermal-photovoltaic system a careful evaluation should be done in order to obtain the best possible yield out of each sub-system (photovoltaic and thermal) and the ratio thermal energy to electrical energy in such a system becomes a very important parameter to consider.

It is the purpose of the present paper to analyze from a theoretical and general point of view three main categories of combined thermal-photovoltaic systems for solar energy conversion. Thermal energy extraction and its relationship to the electrical energy obtained is investigated.

FLAT-PLATE COLLECTOR SYSTEM

Florschuetz (1) has extended the well known Hottel-Whillier thermal model to the analysis of combined photovoltaic-thermal collectors of the flat plate type in which the absorber consists of an array of solar cells to generate electricity while a fluid circulates taken from the absorber and providing useful thermal energy.

It has been shown (2) that for the range of temperatures usually occurring in a flat-plate collector the efficiency of a solar cell can be assumed to behave linearly according to:

$$\eta = \eta_r(1 - \beta_r(T - T_r))$$

where η and η_r represent efficiency at temperature T and at the reference temperature T_r respectively and β_r is the temperature coefficient.

This expression shows that efficiency decreases with increasing cell temperature as in the case of a flat-plate collector where efficiency decreases when the fluid inlet temperature increases.

As a result, maximum overall efficiency for a combined system of this kind can be obtained for working temperatures close to ambient temperature. Assuming values of effective absorptance for the cell covered absorber in the neighborhood of 0.8 and cell efficiencies of 10% it is possible to obtain thermal efficiencies of about 55% with a ratio of thermal energy to electrical energy of 5.

CONCENTRATING COLLECTOR SYSTEM

A well known way to reduce the cost of photovoltaic installations is by means of concentrators of the reflecting or refracting type. In this case, however, efficiency can be severely restricted if operation is performed at high temperatures. On the other hand, concentration is a must in order to increase the temperature for a solar thermal plant and to achieve high energy densities. As opposed to the photovoltaic process, high efficiencies in a thermal installation operating under a Carnot cycle can be achieved only at high temperatures. Neville has studied a system of this type for several levels of concentration (3).

The behavior of such a system is studied and its optimum utilization and range of thermal to electrical energy ratio determined. It is shown that maximum overall efficiencies of some 35% are obtained with a thermal to electrical energy ratio of 2.5 for a concentration ratio of 100.

SOLAR SPECTRUM TRANSFORMER SYSTEM

In this category photovoltaic systems are included in which the total solar spectrum

$$\sum_i N_i h \nu_i$$

does not reach directly the cells but is transformed to some convenient form

$$N_t h \nu_t ,$$

where N_i represents the number of photons per unit time of an average energy $h \nu_i$ in a small frequency interval around ν_i , and h is Planck's constant. This transformation is chosen so as to allow only a narrow band of energy just above the cell bandgap to reach them.

Heating the cells by the excess energy of the higher energy photons is very much reduced in this way, high cell efficiencies can be obtained, and no special cooling system is necessary to keep the cells at a convenient temperature.

In this category two cases may be considered; one in which only electrical energy is obtained from the system with an ideal transformation scheme in the collector

$$\sum_i N_i h \nu_i = N_t h \nu_t ,$$

and a second one in which thermal energy is also obtained from the system,

in this case from the transformer, with an ideal transformation scheme

$$\sum_i N_i h \nu_i = N_t h \nu_t + Q$$

where Q represents the total thermal energy obtained.

The systems described by Bell (4) and Sievers (5) illustrate the principle although the concept is considered here in a more general form. Even when efficiencies depend very much on the actual system considered, this category appears to offer a much greater flexibility as far as the thermal to electrical energy ratio is concerned.

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MULTI-BANDGAP CELLS IN A TPV CONVERTER SYSTEM

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EXTENDED ABSTRACT

Thermophotovoltaic (TPV) Systems and Multi-bandgap Cells are both promising means of increasing solar energy conversion efficiencies [1]. We propose here a typical TPV system coupled with multi-bandgap cells operating with usual cells and usual multilayer non absorbing filters. The TPV converter consists of two facing hemispheres placed every one near the focus of two parabolic mirrors. Sunlight is focused, through a small hole at the vertex of one mirror, into one of the hemispheres and heats it. The hemisphere, made of tungsten, re-emits lower temperature radiation which is directed onto the hemisphere facing. Between the two radiators are inserted one after another, at a 45° tilt from the optical axis, two different non absorbing multilayer filters evaporated on both sides of a Ca F_2 substrate, which reflect onto two separate different cells the wavelength band corresponding to the maximum spectral response of the cells. The I.R. radiation ($\lambda > 1.1 \mu\text{m}$), transmitted by the filters reaches the second hemisphere and heats it. The radiation emitted by this second radiator is reflected by the same filters onto two other cells symmetrically arranged with respect to the first two. In both cases the reflected radiation is focused on the cells. The I.R. outside the reflected bands reaches the first radiator and is recycled. This fraction of energy exchanged by the two radiators is sufficient to keep them at a steady temperature. The whole converter should be in a vacuum to prevent conductive heat transfer. The time-dependent energy balance of the converter has been examined in detail. With a lens 0.5 m^2 in area and a power of 400 W focused on the first radiator, when the tungsten hemispheres have 1 cm and 0.85 cm radii respectively, a steady temperature of 2410 K and 2146 K respectively is reached in 154 s. The power on Si and $\text{Al}_x \text{Ga}_{1-x} \text{As}$ cells is respectively 183 W and 120 W. In any case an overall efficiency of the system of $\sim 45\%$ is predicted. The TPV converter as presented here combines the typical advantage of high efficiency in TPV conversion, that is the transfer of I.R. energy to energy swallowed by the cells, with the advantage of using multi-bandgap cells and a geometrically simple arrangement of the cells. Furthermore, reflecting multilayer filters of good performance are easily obtainable whereas in the TPV converters previously designed either sophisticated

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filters with high transmittance in the band of the maximum spectral response of the cells and high reflectance in the I.R. are needed, or else, sophisticated cells with metallic mirrors on the back.

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SOLAR ENERGY CONVERSIONS: SOLAR-ELECTRIC THERMOPHOTOVOLTAIC
(TPV) SYSTEMS, AND SOLAR-POWERED GAS LASERS

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EXTENDED ABSTRACT

INTRODUCTION

The world's exhaustible energy reserves will inevitably either be depleted or become obtainable only at increased costs and at an unacceptable ecological risk. Therefore, the nation's energy program should be directed toward inexhaustible resources such as: solar, geothermal, ocean temperature gradient and wind energy. This trend is already making itself felt through a more intensive effort in solar energy, not only for immediate applications in home use, but also for industrial applications ranging from solar central power stations to solar chemical processing plants. The possibilities of solar energy applications for aerospace systems of future technology are also being studied; for example: Solar Power Satellites (SPS), Solar-Powered Lasers (SPL) and Solar-Powered Airplanes (SPA).

This paper deals with space and terrestrial solar energy conversions into electricity and into laser radiation through advanced technology. Direct conversion of solar energy into electricity or into gas laser radiation is an inefficient process. This is due to the fact that the absorption spectrum bandwidths of many potential solar cell or gas laser media are narrow in relation to the sun's spectrum. Thus, this work utilized an intermediate blackbody cavity, heated by concentrated sunlight, as the radiation source for the conversions. The potential efficiency of this approach is much greater than that of utilizing sunlight directly.

In the next section a preliminary study is discussed which shows the possibility of a solar-electric thermophotovoltaic (TPV) system. Then research on the concept of solar-powered gas lasers using an electrically heated intermediate blackbody cavity is described.

SOLAR-ELECTRIC THERMOPHOTOVOLTAIC (TPV) SYSTEM

A photovoltaic power conversion system uses solar cells to convert solar energy directly into electricity. The original concept of this method for a SPS was proposed in 1968 [1]. In this concept, a large array of thin film cells would collect solar energy in space where it is converted to microwaves, and beamed to the Earth's surface. High power levels would

require enormous arrays of cells with spectacular cost. Cell number and cost can be reduced by using concentrated solar radiation and high-efficiency solar cells. A TPV system, potentially efficient in principle, can meet these requirements. The feasibility of a solar-electric TPV system utilizing silicon cells has been analyzed [2]. The cell conversion efficiency was predicted to be in the range 30 to 50 percent.

In this work, a solar-electric TPV system utilizing multi-layer solar cells is proposed. This method can improve conversion efficiency and specific power (W/kg) of solar cell even further.

Figure 1 shows the proposed TPV configuration. Concentrated solar radiation heats a spherical blackbody converter (similar to one given in [2]) to a temperature range of 2000 to 2400° K which then reradiates over a spectrum tending toward longer wavelengths. A double-layer solar cell, silicon and gallium arsenide, forming the spherical surface concentric to the blackbody converter, receives the blackbody radiation and converts it into electricity. This system may have a cell conversion efficiency of 50 percent or higher.

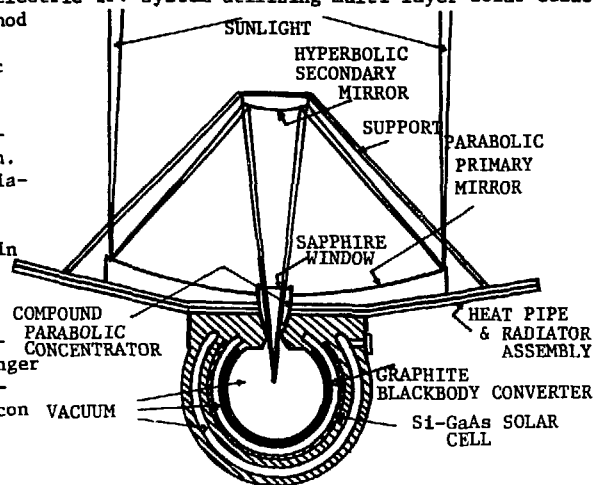


Figure 1. Proposed Thermophotovoltaic (TPV) Configuration.

SOLAR-POWERED GAS LASERS

There is a growing interest in exciting lasers by direct or nearly direct use of sunlight. By this method the working medium absorbs the solar radiation and can lase without the need for an alternate form of energy. The efficient high-power gas lasers (e.g., CO₂, CO and N₂O) that could be used such a device are well-known infrared types. However, direct solar pumping of these molecular systems is an inefficient process, and it would require an excessively large, heavy collector/concentrator and heat exchanger for a given size laser. An attractive solution to this problem is to use an intermediate blackbody cavity, suggested by Christiansen [3]. In this idea, nearly all of the solar radiation is converted by the cavity into the radiation necessary to pump the laser gas enclosed in the cavity, Fig. 2.

To demonstrate the concept, an experiment was performed using the apparatus described in [4] in which solar pumping is simulated by a graphite oven which is heated by an electrical element. A CO_2 -He gas mixture at a temperature of 400°K with pressures of about 1 Torr is enclosed in sapphire tube and is exposed to 1500°K oven radiation. Under this radiation, the gas is optically pumped primarily at $4.3\text{ }\mu\text{m}$, and the optical gain (which is the objective of the energy conversion) is measured by the optical set-up shown in Fig. 3. A CO_2 probing laser ($10.6\text{ }\mu\text{m}$) is used for the measurements. The laser beam is chopped and sent through a beam splitter. Only the signal beam traverses the tube. It is reflected by the end mirror of the tube and its variation under the blackbody radiation is monitored simultaneously with the reference beam on an oscilloscope.

Through calibration measurements [5], it was found that the total active path length and the gas temperature were 91 cm and 400°K , respectively.

For the gain measurements, the same experimental set up was used. A premixed CO_2 -He gas mixture is introduced into the sapphire tube which is kept at constant pressure while optical pumping takes place. Gains with a maximum gain coefficient of $2.8 \times 10^{-3}\text{ cm}^{-1}$ have been measured, Fig. 4

The measurements of optical gain have been found to be sensitive to the power density of the $10.6\text{ }\mu\text{m}$ probing beam. Gain reduction with increased pressure is attributed to a reduction in the mean-free-path of the pumping photons.

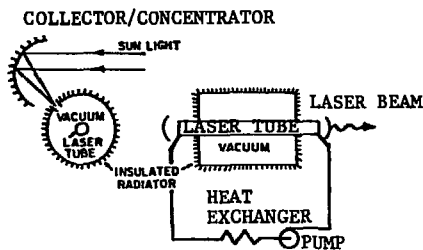


Figure 2. Solar Pumping via Blackbody Enclosure.

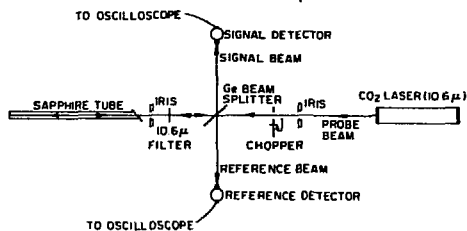
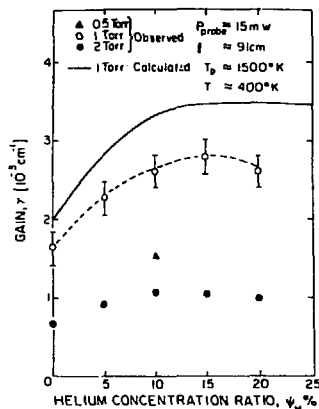


Figure 3. Schematic of Optical Setup.

A simple analytical model is used to predict the gain. Agreement between the prediction and experiment is good, Fig. 4.

Figure 4. Variation of Gain in CO_2 -He Gas Mixtures as a Function of Helium Concentration Ratio.



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STUDIES ON PHOTOVOLTAIC HETEROJUNCTION SOLAR
CELL USING SILICON AND MIXED CADMIUM ZINC SULPHIDE

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EXTENDED ABSTRACT

INTRODUCTION

Surface barrier photovoltaic solar cells are receiving now a considerable interest because of their potentially high efficiency per unit cost, where simple and low temperature processes can be used. A substantial amount of work has been published on CdS - CuS cells, and recently several data have been reported on CdS - InP and CdS - GaAs heterojunctions [1-3]. All data have demonstrated that the electrical and optical behavior of the junction are greatly influenced by the preparation technique, etching process, and other heat treatments.

The aim of the work presented here is to develop a photovoltaic heterojunction between p-type Si and thin film of n-type CdS, and to improve its performance. Optimization of the surface and interface characteristics of the junction was investigated through adding ZnS to CdS and postevaporation heat treatment.

EXPERIMENTAL

Heterojunctions were prepared on the (111) surface of p-type Si single crystal wafers of resistivity about 0.2 to 0.3 ohm cm, 0.35 mm thick, and 5 cm diameters. The wafers were polished to optical finish, chemically cleaned, and oxide layers were removed in vacuum. Pellets of CdS or its mixture with ZnS were evaporated by electron beam heating at pressure of 10^{-7} torr. The crystallographic structure and film nucleation were investigated using x-ray diffraction and scanning electron microscopy. The heterojunction interfaces and transition layers were studied by AES and SIMS techniques. System's performance was determined from $I-V_1$, $C-V$ and sheet resistivity measurements.

RESULTS AND DISCUSSION

The results has shown a strong dependence of the density of interface states and their distribution on preparation conditions and in ambience. Annealing of the CdS-Si junction in H_2S atmosphere at $(10^{-3} - 10^{-4})$ Torr in the temperature range

(350-450) $^{\circ}$ C has improved the structure order (crystalline feature) of the film, and consequently the conversion efficiency η was increased by 1 point. The collection efficiency E has increased also by (6-8) percent. This was attributed to the variation in the optical properties of the CdS film [4]. Further increase in E was observed by using (CdS - ZnS) allayed film (although η and fill factor F_f were reduced).

Optimal sheet resistivity, and maximum interface perfection were achieved by annealing the grown films in hydrogen atmosphere for periods up to 2 hours at temperatures above 200 $^{\circ}$ C. In this way the short circuit current of the initial cell was increased by 30 to 40 percent. Depth profiles obtained by SIMS and AES have shown sharp interfaces due to this treatment. Depletion of Zn from the interfacial connecting layer between the film and Si was also observed.

Further improvement to increase the cell conversion efficiency beyond 13 percent is expected by improving the structural order of the mixed sulphide film from being polycrystalline to epitaxial. This would be achieved after annealing the junction in an atmosphere of dry air and sulphur at a temperature of 350 $^{\circ}$ C or in H_2S at 550 $^{\circ}$ C.

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THE EFFECTS OF JUNCTION DEPTH AND
IMPURITY CONCENTRATION ON ION-IMPLANTED
SOLAR CELLS

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EXTENDED ABSTRACT

INTRODUCTION

A brief survey of the literature dealing with photovoltaic devices yields a vast variety of solar cell types with varying semiconductor materials, metalization schemes, and optical systems(I). However, the bulk of solar cells in commercial usage are now and will continue for some time to be made of silicon.

This paper addresses certain optimization problems for silicon PN junction solar cells. Specifically, it addresses the effects of variations in junction depth and impurity concentration for ion-implanted silicon solar cells on solar cell efficiency.

PROCEDURE

A series of P+N and N+P ion-implanted silicon cells was constructed using a standard physical configuration, process and starting material. These devices were tested for device efficiency and the efficiency compared to that predicted by a simple model under varying solar insolutions(II). Additionally the data generated for diffused junction solar cells in an earlier experiment(III).

CONCLUSIONS

Optimum junction depth and average ion-implanted layer concentration for ion-implanted PN junction solar cells under non concentrated sunlight (approximately AMI conditions) appear to be $0.5 \mu\text{m}$ and $5 \times 10^{18} \text{ atoms/cm}^3$. Variation in solar cell efficiency with junction depth is quite rapid between 0.1 and $1 \mu\text{m}$ with a definite maximum in the vicinity of $0.5 \mu\text{m}$. The variations in response to changes in concentration are minimal. Experiments under changing optical conditions indicate increasing efficiency as insolation shifts from 83 mw/cm^2 to 100 mw/cm^2 .

Comparison with diffused junction solar cells indicates a potentially greater efficiency for ion-implanted solar cells. However, variation in efficiency between individual solar cells is sufficiently great to warrant further experimentation before reaching any permanent conclusion.

The theoretical model (II) utilizing experimentally obtained parameters such as insolation, solar cell saturation current, short circuit photocurrent and material resistivities continues to yield reasonable predictions of device performance as well as provide useful indications of beneficial design changes to meet new conditions. In this latter connection performance of these devices under concentrated sunlight is considered.

I. As example see the various annual proceedings of both the IEEE Photovoltaic Specialists' and annual International Solar Energy Societies' meetings.

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MOS-OXIDE CHARGE INDUCED JUNCTION SOLAR CELLS

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ABSTRACT: Earlier theoretical calculations for the power conversion efficiency of silicon solar cells have established an upper limit ranging between 18-22% at room temperature for AMO operation, depending upon the approximations employed in the analysis. The efficiency of practical solar cells has recently approached about 15%. The large difference observed in the theoretically predicted values and experimentally observed results was identified by several authors. The various fundamental mechanisms dominant in limiting the conversion efficiency of such solar cells were described to be the heavy doping effects such as Auger recombination associated with the band gap narrowing hole life time degradation due to the strained crystal lattice in the n^+ emitter and defects & special inhomogeneity introduced due to several high temperature steps leading to enhanced re-combination.

The work presented in this paper is based upon a theoretical investigation of silicon solar cells employing oxide charge induced junction solar cells viz MOS-Inversion layer solar cells, MOS-ACCUMULATION LAYER SOLAR CELLS and MOS-Vertical Multijunction inversion layer solar cells.

In the present investigation two types of theoretical results are described. First, analytical models of such solar cells are discussed to illustrate the basic operation. In the second part a detailed numerical calculations are performed in terms of device parameters.

On solving the transport equations through these structure it has been established that oxide charge induced junction solar cells have characteristically better performance due to (i) the shallow induced junctions, being free of crystal damage otherwise introduced by high temperature diffusion process allowing high collection efficiency, due to the large electric field existing in the induced layers. (ii) being practically insensitive to surface re-combination velocity and minority carrier lifetime in the n-emitter region,

yielding high open circuit voltage.

The results obtained on the basis of theoretical investigations are compared with the experimentally observed values. The physical mechanisms responsible for the margin in each cells are discussed in terms of technological limits imposed by the fixed oxide charge, excess metal coverage and conventional high temperature induced nonlinearities.

Potential improvements in the device behaviour are suggested employing process variability analysis and alternate-low-temperature processing steps.

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SESSION 5B

SOLAR APPLICATIONS II

SOLAR-POWERED, STRATOSPHERIC, MANNED STATION

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EXTENDED ABSTRACT

The Franklin Research Center's (FRC) concept of a large (<1000 ft. to >5000 ft.) spherical, rigid, vented (constant-volume state), solar-power heated, entrained ambient air, navigable and hoverable aerostat is reviewed [1] and recent work is presented. This aerostat, known as a Solar Thermal Aerostat Research Station (STARS), is able to remain aloft in the stratosphere indefinitely, and contains life support supplies. It may be launched from the surface or, preferably, assembled in the stratosphere. Equipped with nighttime energy storage systems (e.g., water electrolysis), it will be capable of performing a wide variety of long-term, scientific, commercial and strategic missions. Most, if not all, of these missions may be conducted simultaneously due to the unprecedented lift capability of the proposed aerostat. With environmentally clean solar-energized compressed air and/or suppressed electric discharge thrusters, it will be capable of 24-hours navigation and hovering in the stratosphere. Most latitudes may be reached on solar energy alone. With Space Power System (SPS) laser-directed [2] energy to the aerostat, the polar regions may also be included. Residence in the stratosphere is anticipated for an indefinite period (e.g., ~10 years or more).

The STARS aerostat's buoyancy or lift at 20-, 30- and 50-km altitudes, and 26.7°C entrained gas (i.e., solar-heated ambient air) temperature, for a 1-mile diameter aerostat in the constant volume (vented) state based on U.S. Standard Atmosphere 1976 data are 46,000, 8,000, and 200 metric tons, respectively. At 200° entrained air temperature the lift is: 70,000, 15,000 and 750 metric tons, respectively.

The STARS aerostat ceiling condition in the constant (vented) volume state is such that at 20-, 30- and 50-km altitudes and at 26.7°C

entrained ambient air temperature, the tolerable masses (or weights) at these aerostat ceilings are: 27,000, 5,000, and 100 metric tons, respectively. At 200°C entrained ambient air temperature, the masses (or weights) are: 53,000, 10,000 and 500 metric tons, respectively.

The foregoing results indicate that while the 1-mile diameter STARS aerostat can operate at heights of 30 km (for which it was conceived), a larger vehicle would be required to attain 50 km, for an invariant mass. If such an aerostat is at neutral buoyancy at 20 km then it would be impossible to raise the said aerostat above 20 km only if the lift is invariant. However, if the aerostat is designed to operate at higher altitudes, then much of that lift will be in the form of ballast and release of this ballast allows the aerostat to ascend to a higher altitude. In the STARS aerostat this ballast will be compressed ambient air extracted from the environment, so that it can be replaced at any time by the available solar-derived energy.

As conceived, STARS may be assembled in the stratosphere (where the dynamic air pressure is very low, even at high winds). Alternately, assembly may be in a protected earth recess (e.g., quiet lake or crater or open pit mine). Even in a protected environment, some wind loading would be expected. Assuming a 20 mi/hr wind, in a normally directed air stream against a projected-area* of a 1-mile diameter STARS aerostat, a drag force of 20,320 metric tons is produced. Since STARS is not a flat disk normal to the wind, this force is substantially exaggerated. However, even this force is within state-of-the art cable distribution technology.

At operational altitudes the aerodynamic pressure is extremely low, due to the low density and pressure found above the troposphere. The drag force on a normally directed projected area* of a 1-mile diameter STARS aerostat in a stratospheric wind of 50 mi/hr is a relatively modest 30 metric tons. It can be shown that in terms of power this amounts to 1.3×10^6 watts, in contrast to the solar power available on the STARS aerostat of 1×10^9 watts. Hence, navigation and hovering of the STARS aerostat, even in 50 mi/hr stratospheric winds at 30-km altitude, is well within its compressed air and/or suppressed electric discharge thrust engine and power supply capabilities.

*A disk is utilized in contrast to an icosahedron structure to avoid Reynolds number, etc., complications and to emphasize such an adverse target to the wind.

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A Data Acquisition and Instrumentation System for a Solar Industrial Process Heat Installation

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A data acquisition and instrumentation system (ODAS) is being designed and assembled to perform thermal performance evaluation of a solar industrial process heat installation at the refinery of Southern Union Company in Hobbs, New Mexico. The system features are such that it could be used, with some software changes, for most of the solar industrial process heat applications of similar size. The ODAS hardware consists of a data logger which scans the analog signals from the sensors and converts the information to digital form, a 9-track tape recorder which stores the raw data in computer-compatible format, and a modem for communication with a remote computer system. The data logger is programmed in its own language to communicate with the New Mexico Solar Energy Institute (NMSEI) computer facility via a direct dial modem coupled with the common carrier phone system. Data transmittance via a common phone line is being kept as an option while using tapes with recorded data which are retrieved once per week and mailed to NMSEI. The decision to employ recorded data was due to an unsuccessful experience of Southern Union Refining Company with data transmittance through a common telephone line as well as by the advice of the telephone company servicing the Hobbs area. In general the ODAS also has the capability for on-site data reduction and display and is equipped with a backup power supply in the event of power failure. Figure 1 shows a block diagram of the ODAS.

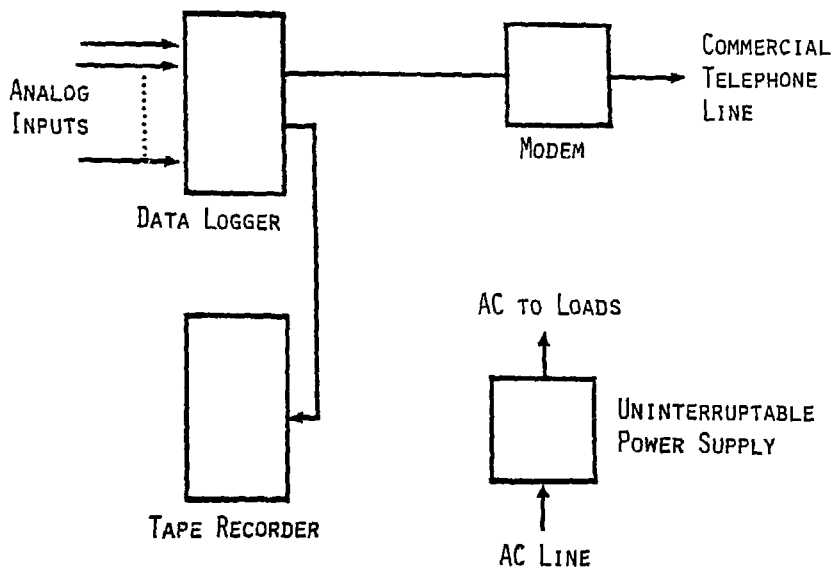


Figure 1. Block diagram of the ODAS.

This on-site data acquisition system (ODAS) was designed to measure the following parameters of the solar industrial process heat installation:

1. Energy to load (steam flow, temperature, pressure, feed water temperature)
2. Parasitic energy (electrical power consumption)
3. Collector array thermal efficiency
4. Heat exchanger effectiveness
5. Pipe heat losses
6. Overall system performance.

The ODAS instrumentation follows the "SHIPS Data Acquisition System Guidelines" by C. F. Kutscher, SERI, March 30, 1979 and the document PB-257 770 of National Bureau of Standards entitled "Thermal Data Requirements & Performance Evaluation Procedure for the National Heating & Cooling Demonstration Program" August, 1976.

Other details concerning the ODAS such as system and sensor calibration, specification and cost will be discussed in the full paper.

POTENTIAL UTILIZATION OF SOLAR ENERGY FOR INDUSTRIAL PROCESSES IN EGYPT

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EXTENDED ABSTRACT

During the last decade, people all over the world are using in alarming rates the costly supply of fossil and conventional fuels as the main source of energy. As the strategic reserves of these natural resources being quickly depleted, it appears as an urgent problem of special importance to mankind to search for alternative natural resources of energy which can replace the conventional fuels in the ever increasing applied fields, which cover every aspects of activity of mankind.

Solar energy, as the inexhaustible major clean source of energy is the only alternative specially because of the large potentials of solar process heat that can totally or partially replace fossil fuels in thermal industrial processes at low temperatures.

A very significant fraction of the total energy consumed in all countries is used in the industrial processes. In Egypt, for example, about 38 % of the total national energy consumption is used in the industrial processes. Fig. 1 shows the national energy consumption. In most industrialized countries this figure ranges from 40 to 55 %. So far, very little attention has been directed towards using solar energy in industrial processes, if compared with the attention given to other solar energy uses, if any. Solar heating for industrial uses, specially at low temperatures, can have real cost advantages since the larger amounts of heat collectable can be used.

Thermal energy in industrial processes can be classified in the application of steam, hot water and hot air. Most of the part of the thermal energy used in industry is at temperatures below 250°C. Fig. 2 shows the low temperature heat consumption in industrial processes. In this temperature range, solar energy technology has developed systems to rep-

place most of the conventional fuel systems. Due to this, the contribution by solar energy would mean large savings in the overall energy consumption for many industries. Geographically, Egypt lies within the sub-tropical region in the Northern Hemisphere (31° - 22° N.). It is one of the countries which has the most sun-shining hours per year, ranging from 3000 to 4000 hours. On the other hand, the total solar intensity incident on a horizontal surface ranges from 4.6 to 8.4 KWH/m² day at lower Egypt and from 7.2 to 10.8 KWH/m² day at upper Egypt. Solar industrial process heat, in our case, will not be affected by the small seasonal variations but due to diurnal variations, some thermal storage system would be necessary for continuous production.

Various solar collecting devices appropriate for our climate are the liquid flat plate collectors with black paint or selectively coated-single glazed makes the most economic sense in terms of useful energy capture per capital cost unit outlay. For the production of minimum temperature steam, simple and relatively low cost stationary parabolic concentrating collectors can be utilized. In order to achieve temperatures over 250°C with reasonably good efficiency the tracking parabolic concentrators would be necessary.

The most promising industries needed for our economy that can utilize solar/or solar-assisted process heat systems in some of its stages are; crop drying, food processing and canning - textile industry - chemical industries (plastics, soap and organic dyes) - petroleum refining (preheating of crude oil prior to distillation, stabilization and removal of H₂S and light gases).

This investigation gives a survey of the possible utilization of solar energy in various industrial processes. The main objectives of the study are:

- 1- Characterization of the requirements for each industrial process.
- 2- The choice of the suitable applications of solar systems.
- 3- Computations of the expected performance of solar systems of various designs that could be used.
- 4- Economic comparison of the different solar systems.
- 5- Prediction of cost savings.

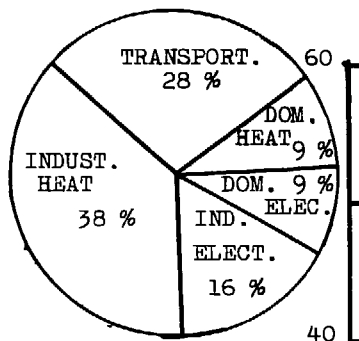


Fig. 1 NATIONAL ENERGY CONSUMPTION.

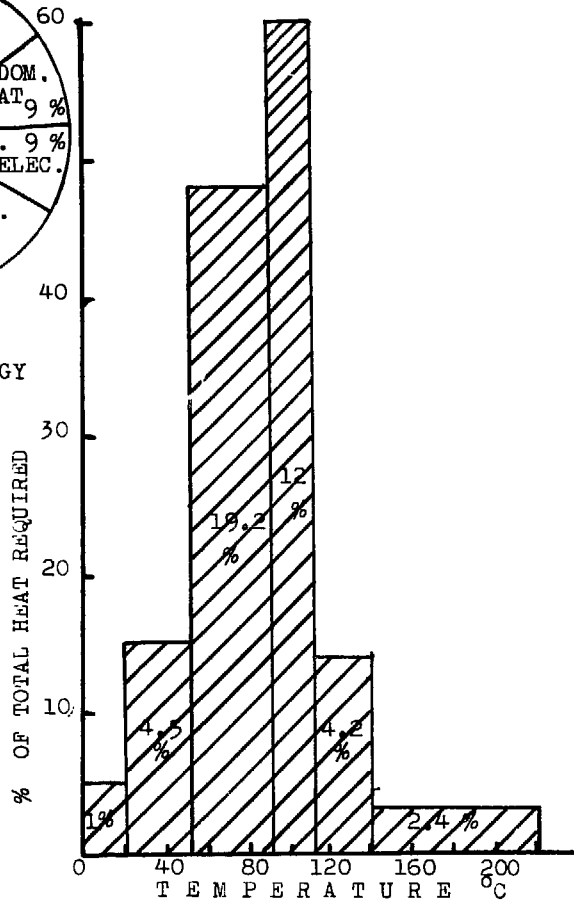


Fig. 2 LOW TEMPERATURE HEAT CONSUMPTION

THE USAGE OF HEAT PIPES IN SOLAR ENERGY

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EXTENDED ABSTRACT:

INTRODUCTION

A heat pipe consists of a closed-tube, a porous wick and a working fluid. The wick is held tightly and uniformly against the inside wall of the pipe. Sufficient working fluid is put into the tube to wet the entire wick structure and the air in the pipe is evacuated. To one end of the pipe heat is added vaporizing the working fluid which in turn flows down the central core of the pipe to a somewhat cooler end called the condenser. At the condenser end the vapor is condensed to the liquid phase and releases the associated latent heat. The condensed liquid is pumped back to the evaporator section by the action of the surface tension in the capillary structure of the wick material.

The evaporator section together with a linear concentrator can be exposed to solar radiation while the condenser section is put in a water tank. The working fluid in the heat pipe will then transfer the solar energy to the water tank via phase transition.

The performance of the pipe will definitely depend on the choice of the lengths of the evaporator and the condenser sections for a particular heat pipe. For the case of improper choice of lengths, the pipe may not be operational for the entire length or condensation may occur where it is not desired. The amount of the working fluid will also alter the performance. When excess or little fluid is put in the pipe it may block the pipe or one may have un-wetted regions in the pipe.

This research has started with the aim of finding a proper condenser to evaporator length ratio for an optimum mass of the working fluid.

PROCEDURE

Copper tubes of 2.5 cm are used for the fabrication of the heat pipes. Copper screen having 290 pores per square centimeter is used as the wick material and water is used as the working fluid. The pipes are evacuated to 10^{-3} Torr before sealing.

The evaporator length is kept constant while the condenser length has been taken as a variable. Different amounts of water is put into the heat pipe and the amount of energy transferred to the water tank is measured. Thermocouples are placed along the surface of the pipe to get information on the mode of operation of the heat pipe. Other thermocouples are placed within

the furnace which is kept at a constant temperature and used to supply heat to the evaporator section.

CONCLUSION

For the purpose of detecting if there is a critical ratio of the condenser length (l) to the evaporator length (L), a graph of the rate of increase of the temperature of the tank by convection is drawn versus l/L for different amounts of the working fluid. We have the tendency of concluding that for a normal operation and to deliver the maximum amount of heat to the water tank the ratio should be around 0.2-0.3 and the working fluid should be taken as 20 cc. However in order to make a more concrete conclusion we will continue for further research.

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Performance Evaluation of a Retrofitted Solar-Assisted
Heat Pump System in a Hot/Arid Climate

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EXTENDED ABSTRACT

The combination of a solar system with a heat pump system has numerous advantages. The two systems are complementary, offsetting weak points apparent when either is used alone. A solar-assisted heat pump system achieves the following: 1) a high coefficient of performance (COP) resulting from a high and relatively constant source temperature for the heat pump, 2) ability to use less expensive collectors or smaller collector areas than in a solar system alone, and 3) a heat pump that will not be oversized for cooling, thus maintaining a high heat pump COP throughout the year and potentially saving a substantial amount of electricity.

Climatic conditions, however, can have a significant impact on performance of a solar-assisted heat pump system. New design schemes are needed which capitalize on weather conditions so that the system ultimately benefits from them. To investigate the impacts of the climate to the heat pump system, a 3-ton ECOSOL water-to-water heat pump unit was retrofitted to the university's active solar house at New Mexico State University in Las Cruces, New Mexico. The schematic of the solar-assisted heat pump system is shown in Figure 1.

The system was instrumented and real time performance data was collected; this real time weather and system data was then used to modify a solar-assisted heat pump program called SYRSOL--a program developed by an engineering research team at Syracuse University. With the modified program, the yearly performance on the house and the system was determined. Figure 2 shows the energy and the load distribution of the system at a typical day operation on March 2, 1979.

Study objectives were to obtain results of the performance of the solar-assisted heat pump system operated in a hot/arid climate and to obtain experience with operation and maintenance of the system. Economic evaluations using present worth theory and payback analysis compared the system to other conventional heating modes such as a natural gas furnace, oil furnace, conventional heat pump, and electric furnace.

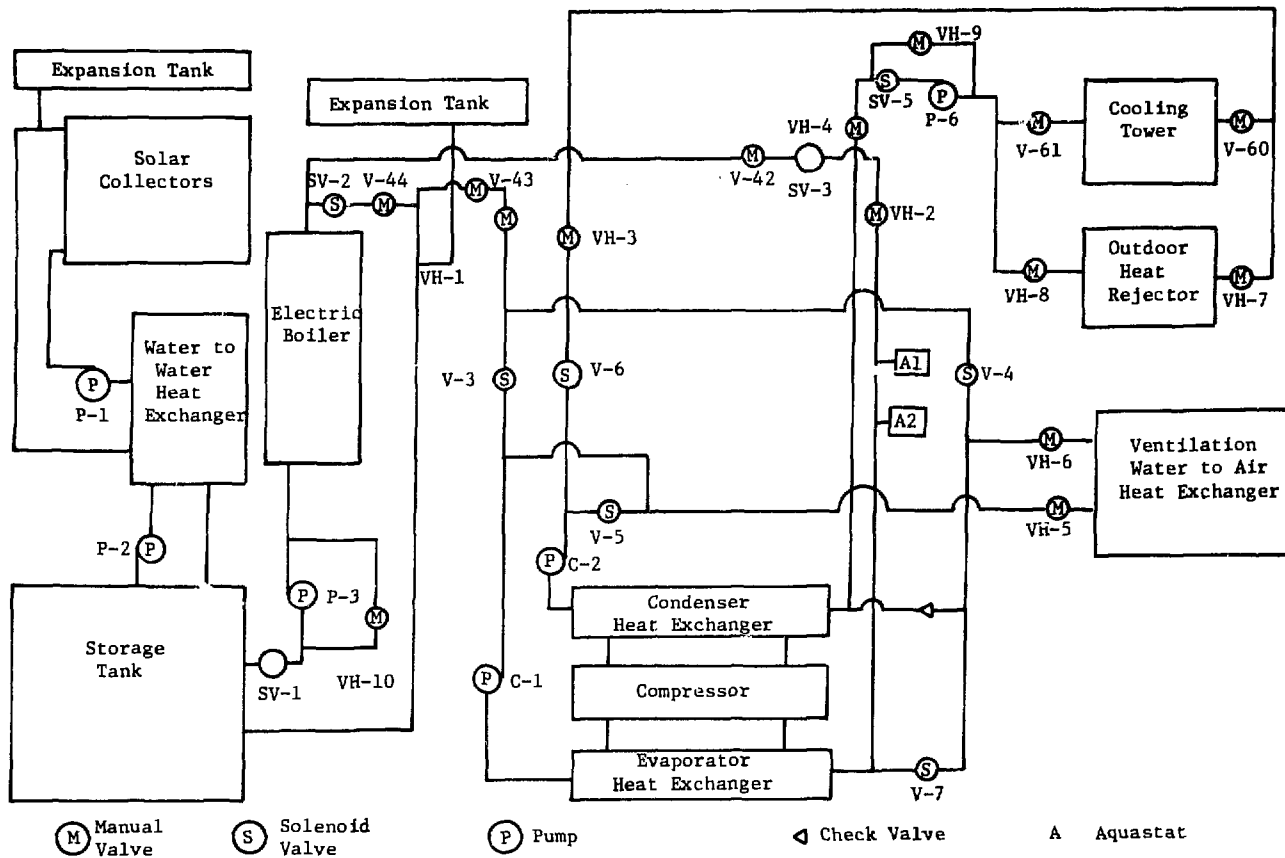


Figure 1. Schematic of the Solar Assisted Heat Pump System at New Mexico State University Solar House

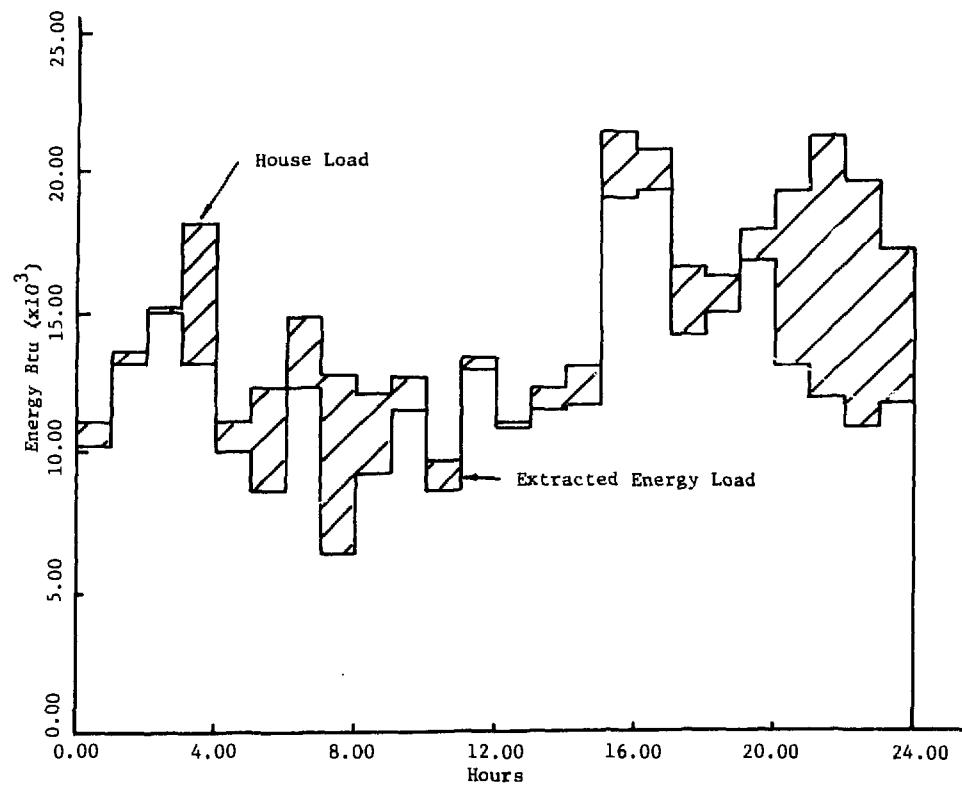


Figure 2. Spectrum of Energy Loads/Supplies of the Solar House on March 2, 1979

THERMAL ANALYSIS AND OUTLINING OF AN
EXPERIMENTAL SOLAR ASSISTED HEAT PUMP

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EXTENDED ABSTRACT

SYSTEM AND BUILDING DESCRIPTION

Within the Progetto Finalizzato Energetica, the Italian CNR has financed a study on the feasibility, both energetical and economical, of solar assisted heat pump systems in Italy. For the experimental part of the study the spaces to be conditioned and the heat pump system, with its modes of operation, had to be selected.

According to the present state of the art a flexible system has been designed, Fig.1. Two kinds of flat plate solar collectors are used alternatively in a 15% monoethylenic glycol water solution loop. 12 m² corrugated aluminium single glazed collectors are south faced at 50.85° from the horizontal (that is latitude plus 10°) and 30 m² extruded black rubber, unglazed and quite bare, collectors are laid horizontally.

A flat plate heat exchanger connects the collection loop to the storage loop. Water in both the loops has been treated with corrosion inhibitors.

There are two non pressurized fiber-glass water storage tanks, each with a capacity of 1.8 m³. Their thermal insulation is obtained by a jacketed wall filled with a 6 cm of polyurethane foam. One tank contains water at higher temperature for direct solar heating by the solar heat exchanger and the other contains water at lower temperature for feeding the water-to-refrigerant evaporator of the heat pump.

In the supply air duct there are a water-to-air heat exchanger for the direct solar heating, the condenser of the heat pump (winter operation), a pan humidifier, the two stages (5+5 kW) auxiliary and back up electric resistances.

The heat pump is the Delchi USH036 type, suitably modified. It has two parallel evaporators which allow it to operate, du

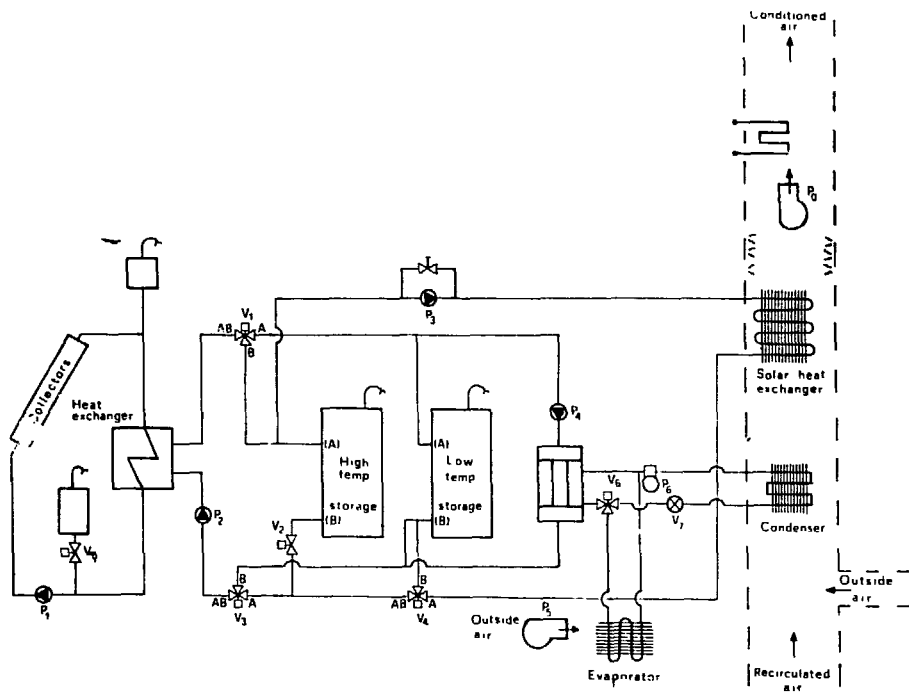


Fig.1. Simplified diagram of the system.

ring the winter, as both a water-to-air and an air-to-air heat pump. The water contained in the lower temperature tank and the outside air are the heat sources for the two operating modes.

These sequence winter operating modes have been chosen: direct solar heating, water-to-air heat pump, air-to-air heat pump. The temperature of the water contained in the two reservoirs selects the operating mode. In summer operation the heat pump acts as a conventional air-to-air conditioning unit with the reheating coil fed by the high temperature storage.

The conditioned spaces consist of three offices and a laboratory, obtained by modifying an existing large room, Fig.2. The floor area is 64.5 m² and the volume is 187 m³. The entire east and west faces consist of double-glaze windows shaded by venetian blinds with light colored slats extending from the

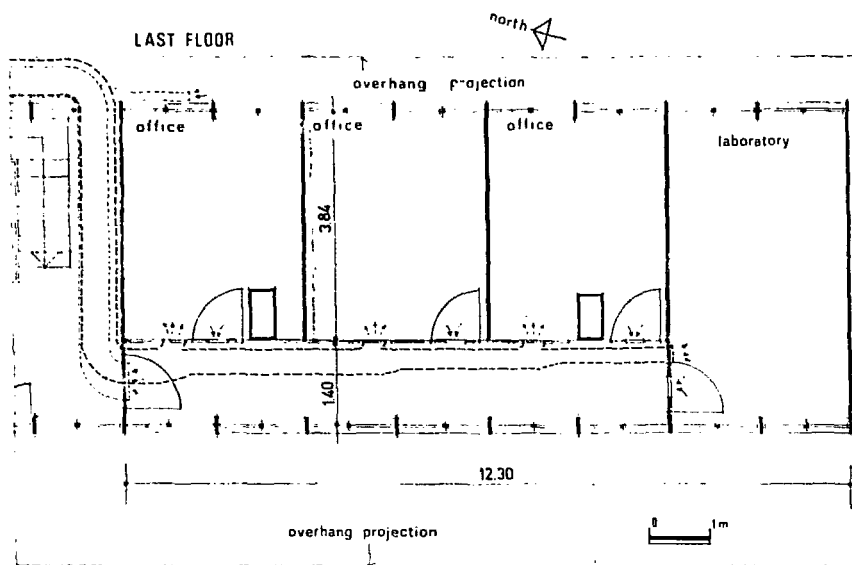


Fig.2. Plan of the conditioned spaces.

floor to an height of 2.3 m; during the summer they are shaded by large overhangs. North and south brick walls divide the building from some non conditioned rooms. The massive roof is partly shaded by the solar collectors. The massive floor divides the conditioned space from other conditioned rooms. The total thermal transmittance of the building is 483 WK⁻¹.

THERMAL ANALYSIS

The peculiar aspect of the conditioned spaces required a careful estimate of the heating and cooling seasonal energy demand. The proposed room model consists of two capacitive layers - floor and ceiling - two adiabatic opaque layers and two double-pane windows partly shaded by closed venetian blinds and overhangs. The short-wave and the infrared cavity radiation problems are disjointed. Solar fluxes are first determined by the net-radiation method. Then the heat balance node equations are solved by an explicit scheme. The forcing insolation and outdoor air temperature vary hourly following a long-term monthly mean pattern. Monthly means of hourly energy needs and inside air temperature are determined respectively for system operating and non-operating periods.

PERFORMANCE OF A CLOSED LOOP EARTH
COUPLED WATER SOURCE HEAT PUMP

Abstract

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In this paper a description of an inexpensive earth coupled water source heat pump system is given along with experimental data collected during the 1979-80 heating season. The system uses a commercially available water source heat pump which is coupled to an earth-type heat exchanger. The heat exchanger is located in a simulated soil absorption field used with household sewage disposal systems. Two types of earth coupled heat exchangers were experimentally tested. One consisted of 400 ft of four-inch diameter PVC pipe while the second exchanger had 200 ft of two-inch diameter cast iron soil pipe. Both exchangers operated satisfactorily. The simulated absorption field, which is 100 ft long, 6 ft wide and 3 ft deep, was constructed according to standards established for domestic sewage disposal systems which use septic tanks. The absorption field (or drainage field) described above has approximately one-half the surface area required to service a two-bath house used by four occupants in the Raleigh, North Carolina, area. The heat pump is located in an instrumented calorimeter house, measuring 24 ft by 16 ft in floor area, which has a heat loss rate of 8693 BTU/DD. Consequently, the total heat loss from the calorimeter house is similar to those expected from a 1100 sq. ft house which has the recommended amount of insulation and located in an area which has an outside design temperature of 10 to 15°F.

The COP of this system for the 1979-80 heating season was 3.75 based on Degree Day data. As a consequence of the favorable COP obtained, in addition to the low cost of adding the earth coupled heat exchanger and circulating pump if they are put in place when the septic system is initially installed, makes this type of system competitive with conventional heating systems such as an oil or gas fired furnace.

In addition to a description of the system, a detailed energy utilization and cost effectiveness comparison is made to other types of conventional heating and cooling systems. A comparison is also made between a heat transfer model proposed for the earth coupled heat exchanger and the experimentally measured performance of the earth coupled heat exchanger.

SOME HEAT PUMP CONCEPTS FOR RESIDUAL HEAT UTILIZATION*

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EXTENDED ABSTRACT

INTRODUCTION

Large quantities of low temperature heat in the industrial sector are rejected in the cooling water, condensate, and process water streams. While the energy rejected in these streams at temperatures between 40 and 80°C amounts to 2.95×10^9 GJ/yr, 2.42×10^9 GJ/yr of process energy in the form of hot water and steam are needed in the United States. Industrial heat pumps, that recover the low temperature heat energy and upgrade it to a more usable temperature level, may improve the energy supply and demand situation. Two heat activated heat pump concepts -- an absorption cycle system and an open cycle system are analyzed from the conceptual systems design and energy savings point of view. The results of the analysis and further research needs are presented.

THE SYSTEMS

An Absorption Cycle Heat Pump. Process heat in the form of hot water can be generated by a heat-activated absorption cycle heat pump. The schematic and process variables of such a system generating 1kg/s of hot water at 105°C from a source at 60°C are shown in Fig. 1.

In this cycle (Fig. 1) waste water at 60°C is flashed in absorber I. The steam produced is absorbed by a concentrated LiBr-water solution. The heat released in the absorption process is used to heat water that is sent to a second stage and divided in two fractions. One is further heated to 105°C in absorber II, and delivered as useful output. The remaining fraction is flashed in absorber II, which works in a similar way to absorber I. The flashed water is mixed with make-up water and returned to the absorber I for reheating. The dilute LiBr-Water solution is pumped to the open regenerator via recuperative heat exchangers. In the regenerator, water is evaporated into the air by heating the solution with waste heat. Part of the thermal energy delivered to the air is recovered in an air recuperative heat exchanger. An open regenerator was chosen since regeneration may proceed in summer days with low solution temperatures.

The cycle thermal efficiency is 25%, not accounting for parasitics. Reasonable values of heat-mass exchanger effectiveness were adopted. Equilibrium of vapor pressure between the steam and the solution was assumed at the absorbers outlet. The regeneration was assumed to take place at

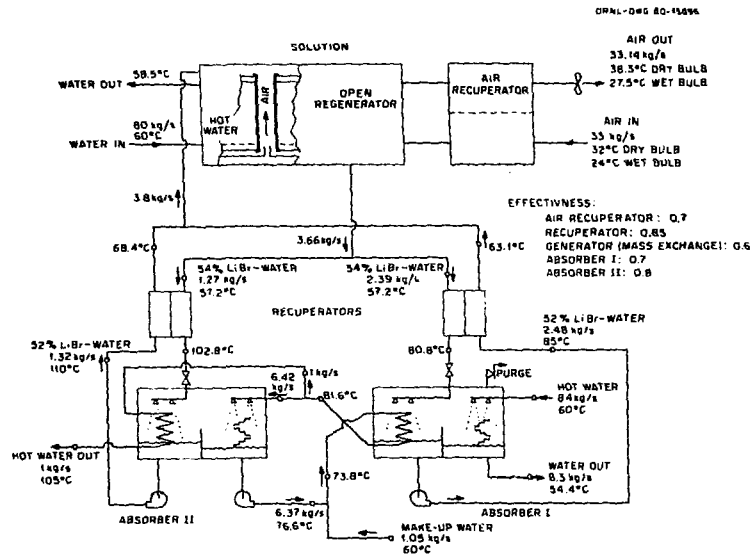


Fig. 1. Absorption Cycle Heat Pump

constant solution vapor pressure. It was also assumed that the solution temperature is maintained close to the waste heat temperature during regeneration.

In conclusion, it may be said that absorption cycles may be employed to recover waste heat and boost its temperature without large inputs of shaft work. Whereas the absorbers and recuperators are standard components, the need for operating at high solution concentrations calls for development of the regenerator. In an open regeneration, low temperature waste heat may be used and no cooling water is needed for vapor condensation. Potential corrosion problems should be studied and controlled.

An Open Cycle Heat Pump. An open cycle heat pump may be employed for low pressure process steam productions from uncontaminated cooling water. A heat activated open cycle heat pump is simply a combination of an open cycle power system and an isothermal steam compressor. A schematic of the system is shown in Fig. 2. In Fig. 2, a small fraction of the warm water from a residual heat source is flashed into steam at the evaporator. The steam flow is divided into two streams. The first stream goes to a turbine to power the accompanying steam compressor and generate auxiliary power. The turbine exhaust is condensed at the condenser. The second stream goes to the compressor where the pressure and saturation temperature are elevated by mechanical compression and the low pressure process steam is produced. To reduce the mechanical compression work, a quasi-isothermal compression using interstage water spray is selected.

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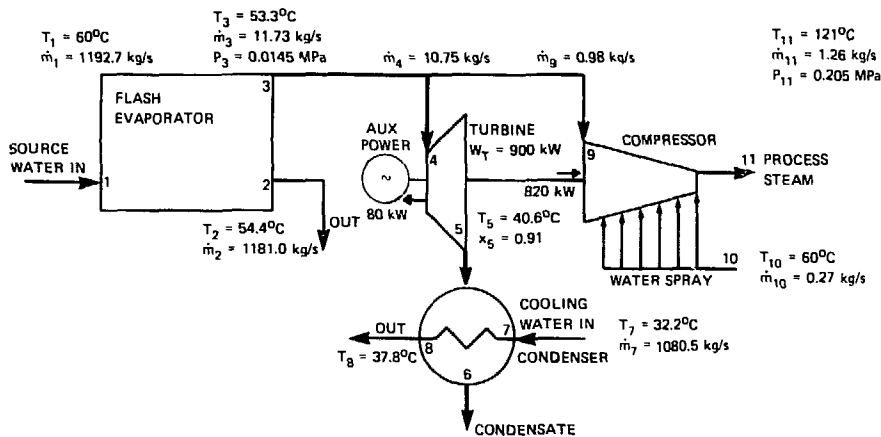


Fig. 2. Schematic of a Thermally-Driven Open-Cycle Heat Pump

The system state variables in Fig. 2 are computed for generating 1.21 kg/s (10,000 lb/h) of 121°C (250°F) low pressure process steam from a heat source of 60°C uncontaminated cooling water. With the given thermodynamic states, the power turbine is based on Balje's N_G - D_S design approach and the compressor is designed with the aid of manufacturer's technical data. The heat pump output equals 2940 kW.

The thermally driven open-cycle heat pump can be an effective device for utilizing low temperature residual heat, since it produces usable energy without the consumption of additional primary energy. Due to the inherently low thermal efficiency (5.3%), such heat pumps can only be applied where ample waste heat is readily available. According to the analysis of the model heat pump system, the derived design parameters of the major components are within the state of the art. A field test of a demonstration unit may prove to be useful to reduce the uncertainties in the analysis.

ECONOMICS OF HEAT RECOVERY

The cycles analyzed recover the waste heat by upgrading a fraction of it, and rejecting the remaining fraction at a lower temperature. The capital investment that may be outlayed for a desired return on the investment (ROI) was calculated using the discount cash flow technique. A plot of capital investment versus the ROI can be made. For the assumptions of this analysis, a capital investment on the order of \$900,000 is possible for an ROI of 15%, for a 2940-kW heat pump.

AN INVESTIGATION OF ENERGY CONSUMPTION BY AIR CONDITIONERS
AT THE UNIVERSITY OF IFE, NIGERIA.

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EXTENDED ABSTRACT

INTRODUCTION

Although Nigeria is an oil producing and exporting country, it has been experiencing various forms of energy problems. This could be attributed to the influence of higher revenues which the country have been receiving since the 1974 OPEC oil price increases.

Nigeria's oil wealth has resulted in rapid changes in the mode of energy utilisation by her inhabitants. This is principally in relation to lifestyle of Nigerian citizens. For example, before the emergence of the present oil boom in 1974, most Nigerians in the middle income bracket would probably own a bicycle or motorcycle. At present, a large majority of people in this income bracket can conveniently afford to buy and maintain cars. This wealth has also reflected in the purchasing power of most Nigeria for energy consuming targets. The Federal government and other State governments have also spent several billions of Naira (n1,0=US\$1.837) in national development programmes. Through these programmes, large scale construction projects have been going on in the country since 1975. When these projects are completed and put into use, they will immediately open up more avenues for the consumption of the country's energy resources. For example, the Ajaokuta Steel Complex which is being developed with the aid of Russian experts will require several gigajoules of energy for its activities.

As a result of rapid increases in the trend of Nigeria's energy consumption, very often these constitute major economic problems in the country. For example, electricity supply which is essential for the economic survival of a country is very often in high demand with the result that the National Electricity Power Authority (NEPA) are not able to cope with the demands. In order to solve this serious problem, load-shedding was introduced. This is a method of

systematic sharing of the electricity available to all parts of the country. To achieve this, a programmed 'cut-off' system was introduced. Although this was thought to be an immediate solution to these high demands, this has not worked effectively. The most common fault has been the incidence of voltage fluctuations which leads to the damage of most electrical equipments if adequate safeguards are not taken.

Electricity consumption in most offices in Nigeria are mainly through the use of airconditioners. A detailed study of the energy consumption by these equipments were carried out in office buildings at the University of Ife over a twelve month period (rain and dry seasons),

FIELD STUDIES AND RESULTS

In order to assess more precisely the degree of energy consumption by airconditioners in office buildings at the University of Ife, it was necessary to have an insight on the thermal comfort levels which are acceptable by workers in the offices used for this investigation.

Thermal comfort can be defined as that condition at which the human body expresses satisfaction with the environment to which it is subjected. Factors such as temperature, air movement, humidity, and radiation will influence the degree of thermal comfort of the human body. Apart from questionnaires which were used in the evaluation of responses to thermal comfort of office occupants, all the factors mentioned above were monitored during the course of this investigation.

The magnitude of energy consumption by the airconditioners were studied. The main paper of the conference will give the results of this investigation and suggestions for avenues of reducing energy consumption in airconditioned offices.

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SESSION 6B

SOLAR APPLICATIONS III

UTILIZATION OF SOLAR ENERGY
TO INCREASE THERMAL COMFORT IN BUILDINGS

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EXTENDED ABSTRACT

INTRODUCTION

Theoretical and experimental analyses and studies of enclosures with respect to assessing their thermal environments have been studied rather extensively within the last decade and is given in [1]. Additionally, also within the last decade, applications of solar energy for heating and/or cooling of buildings acquired unprecedented importance. This has manifested itself in various publications in relation to energy conservation [2]. Recently, an experimental analysis of thermal comfort in classrooms for purposes of energy conservation has been presented [3]. It is felt that a need exists for bridging the gap between the thermal comfort concepts and better and more use of solar energy to obtain this desirable condition.

THERMAL COMFORT

An enclosure is considered to have an optimum condition of thermal comfort when the Predicted Percentage of Dissatisfied (PPD) is 5% for a Predicted Mean Vote (PMV) of neutrality [1]. For practical purposes, deviations from optimal are allowable and a PPD of 8% and a PMV of ± 0.35 seem to be reasonable for project planning purposes.

Thermal comfort is dependent on a number of variables. The most important ones are the activity level - heat production in the body [4], the thermal resistance of the clothing, the dry-bulb air temperature, the mean radiant temperature - defined as the uniform surface temperature of an imaginary black enclosure with which the occupant also a black body exchanges the same heat by radiation as in the actual environment [5], the relative air velocity and the water vapor pressure in the ambient air.

Utilizing the equations which characterize thermal comfort, the required air, clothing and mean radiant temperatures may be obtained for certain given activity levels, clothing, relative air velocity and the water vapor pressure in the ambient air. These temperature requirements, therefore, dictate how the

various parts of a building, from a one family house to a high rise, can be zoned for heating and/or cooling purposes. This is where effective utilization of solar energy acquires importance.

SOLAR ENERGY

Various means of harnessing solar energy exist today to do certain jobs. The designed for heating and/or cooling loads are, however, calculated with no reference to thermal comfort. As a matter of fact, very few if any designs are made considering comfort criteria as a whole. It is here that the DISCOMFORT is perpetuated even while the most important methodologies are used for general calculations and designs. As a result, most of the harnessed solar energy is wasted on heating and/or cooling of enclosures and not utilized for other more effective areas of application. No conservation of this inexhaustable source of energy is thought of and wastefulness, in a different context, continues.

In order to effectively utilize solar energy, a certain design sequence must be followed; design for comfort and design for solar energy utilization must be integrated. To do this, a very detailed analysis of the total enclosure as well as the individual sections must be made. Once the required temperature in every part of the enclosure is known, then the load for each can be accurately calculated. Utilizing these load requirements, zoning of the conditioning systems can be made. The solar system design can now be developed to satisfy the various loads in all of the zones. The rest of the harnessed solar energy may thus be converted to areas where other uses and needs exist. It is anticipated that even larger amounts of conservation could be obtained in such a design. The engineer must strive for comfort since this is what is required by the people along with maximum conservation and minimum cost.

What is needed, of course, is an actual design which will make it possible to combine the requirements of comfort and total utilization of solar energy to satisfy these criteria. There is a concerted effort in this direction now and hopefully many meaningful and easily usable methodologies can be developed. Unless successful criteria are obtained, no engineer and/or architect will pay much attention to this overall systems point of view and the resulting design, to thermal comfort ideas or to utilization of solar energy.

CONCLUSIONS

Various independent studies of thermal comfort and effective utilization of solar energy for heating and/or cooling have been successful individually. The ultimate desire is to be

able to come up with an overall system design bridging these two to create the optimum conditions. Soon some preliminary results will be obtained and fundamental but yet simple to use methodologies will be developed.

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POWER SAVING IN SOLAR ABSORPTION COOLING SYSTEMS

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ABSTRACT

Solar Absorption Cooling Systems are viewed as potential future systems that would reduce the current dependance of cooling systems on conventional energy sources. Of particular interest in Solar Absorption Cooling System is the amount of power consumed per unit of 'end use' refrigeration as compared to that consumed by conventional vapour compression systems.

The sources of power consumption in both vapour compression and solar-dependent absorption cooling systems are discussed and their contribution to the total power consumption per refrigeration unit is determined. The effects of the cooling and chilled water temperatures on the performance and power consumption of both systems is discussed. It is shown that, under certain conditions, the power consumption per refrigeration unit in both systems is equal. Two descriptive diagrams of the power consumption in both systems are presented and could be used to determine the feasibility of using either.

THE SOL-TEMP SYSTEM

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ABSTRACT

A new concept of building design utilizing a 'total energy' solar collector is currently under patent pending.

The solar collector is a hybrid air system that is integrated into the walls or skin of a structure for both window 'See-Through' and 'Solid-Wall' applications. Other variations are possible for office buildings, industrial, greenhouse, and mobile home applications.

Thermal storage and collector with back up are provided in a single modular plug-in unit that fits into standard construction dimensions.

The device has 6 conventional modes of operation: Direct Heating, Heating from Storage, Space Ventilation, Cooling, Collector Venting and Heating from back-up. The 'See-Through' unit provides control of natural illumination, a very low 'U' factor thermal barrier and zone temperature control.

The 'Solid-Wall' system has both air and water heating capability within the unit and one variation permits using a masonry wall as a thermal storage and radiator system.

Both the 'See-Through' and the 'Solid-Wall' systems are retrofittable with photo voltaics for electrical energy conversion and designed as rapid replacement units.

The 'plug-in' modular concept enables rapid, moderate skill level installation by construction tradesmen or handymen. It is designed to be factory assembled, wired and checked. System cost is expected to reduce conventional cost of new solarized structures because it eliminates need for: separate back-up stove, conventional hot air furnace, thermopayne windows, air conditioning, shutters, and separate solar domestic hot water equipment. Energy savings start immediately. Capital equipment costs, payback periods, tax credits, are no longer a deterrent to solarize with Sol-Temp.

Electrical resistance heaters built into a separate thermal compartment provide the thermal back-up by making use of utility base-load power. Back-up to the electrical utility would be provided by batteries.

Auxiliary reflector systems provide solar collection enhancement and are adjustable and storable for diurnal and seasonal changes of sun position.

Special features include a unique front glazing design and high absorptivity and low emissivity absorber system.

System efficiency is expected to be significantly greater than add-on installations.

Sol-Temp is a unique energy 'skin' concept designed to collect, store and supply energy at the exterior perimeter of a building wall instead of transporting energy to a remote basement or storage for later distribution. In effect, the building 'skin' provides the energy needs for the room occupants directly, eliminating the usual distribution and storage losses.

THE KENTUCKY SOLAR HOUSE:
A FLEXIBLE EXPERIMENTAL TEST BED

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EXTENDED ABSTRACT

INTRODUCTION

The Institute of Gas Technology (IGT) is testing a solar house located in Lexington, Kentucky (heating degree days = 4683). This facility is one of the most comprehensive residential solar test facilities in the United States. The facility was designed primarily for studying and evaluating the interface between active and passive solar space conditioning systems with various residential heating, cooling, and water-heating systems under strictly comparable conditions. The heat load characteristics of the structure has been determined, and the base line solar-assisted heat pump parallel configuration (SAHP-P) has been monitored, modeled, and analyzed.

THE SOLAR TEST FACILITY

The solar test facility is equipped with a forced air heating system using an active air system with 640 ft² of double-glazed collectors operated in parallel with a five-ton air source heat pump. The facility has a rock bed thermal storage system and a solar preheat domestic hot water system. A second south-facing roof of 600 ft² is available for future experimentation. Space is available for a second water, rock, phase change, or chemical reaction thermal storage system. Construction of the facility was begun in May 1977 and completed in March 1978.

The heated living area is 3528 ft². There is an additional 2015 ft² (8-ft high ceiling) in the basement for solar related research activities. The basement accommodates all the conventional and solar heating and cooling equipment and a complete workshop. All windows are double-glazed and weather-stripped. Total window area is 373 ft² with 47% of the window area on the south, 32.2% on the north, 12% on the east, and 8.8% on the west.

The test facility is instrumented to determine solar energy system performance, building heat loads, and backup system performance. The flexibility inherent in this facility allows the conduct of a program that ranges from relatively simple systems monitoring to a long-term R&D program, including a high level of sophisticated load management for a number of solar system design options. Furthermore, because the component accessibility is designed into the solar home, maintenance, repair, and system modifications are greatly facilitated. The basic systems have been operated and tested for two years, so system performance and reliability is established. The 1-1/4 acre that surrounds the facility provides an opportunity to add large storage tanks, pools for a low-grade heat source, or sink, and ground coupled heat exchangers for heat pumps. The facility incorporates a unique and innovative all-air, solar-assisted heat pump design configuration. This configuration allows seven solar operational modes to operate (see Figure 1).

DISCUSSION

Building heat load has been determined experimentally to be 1100 Btu/hr-°F (26,400 Btu/DD; 7.48 Btu/DD ft²). The base line solar-assisted heat pump parallel configuration (SAHP) is under investigation. The SAHP configuration uses Modes 1, 2, and 3 with the conventional heat pump as a backup (see Figure 1). Other operating modes will be evaluated after the tests on the parallel heat pump configuration are completed. The building was run in an electric resistance heating mode to gather heat load values. Calculated values for the heat load have been in close agreement with the measured values. A computer model for determining building heat load requirements and reducing solar and backup system performance data was then developed. This model takes into account passive solar inputs to the structure. Substituting the hourly data generated from the SAHP configuration into the computer model provided the direct solar input, passive solar input, and heat pump input fractions on hourly, daily, and monthly basis.

From the actual kWh consumed by the heat pump, the average COP of the heat pump in the SAHP configuration was calculated. This value is compared to the COP of the stand-alone heat pump configuration and to the heat pump manufacturer's steady state COP values. The effect of the SAHP configuration on the heat pump COP will be presented and the effect of load management in improving the COP of the heat pump in the SAHP configuration will be discussed.

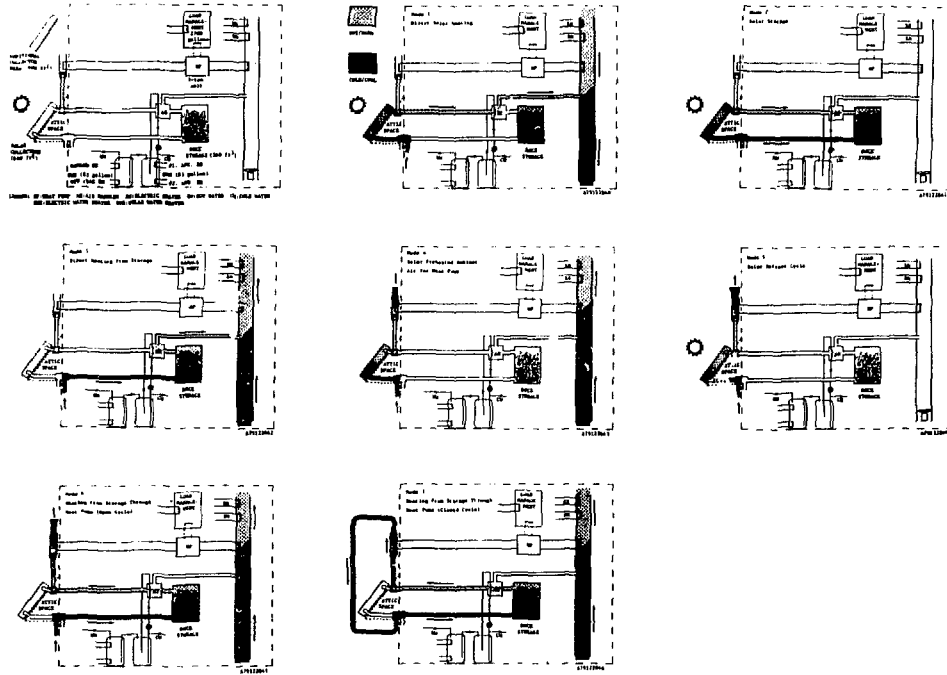


Figure 1. Solar System Components and Various Solar Operating Modes

LOW COST SOLAR CONCENTRATOR FOR DOMESTIC USE IN DEVELOPING COUNTRIES

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EXTENDED ABSTRACT

INTRODUCTION

Common man is becoming aware of the utility of solar energy mainly because of shooting prices and non-availability of conventional fuels; but for using solar energy he wants a device that is simple and within his budget. Therefore development of devices that can be locally fabricated, easy to handle and are cheap has also become equally important. Looking to the results obtained from the present energy development programmes of the world over, it appears that it will take some time to develop reliable and efficient photovoltaic devices. It will take still more years for this technology to reach individual homes in developing countries. On this background the method of fabricating a low cost concentrator given in the present paper becomes significant.

SOLAR BASKET M. von Oppen (1977) has described a 'solar basket' made of paper machee, but it requires a paraboloid solid cement mould for the construction of the basket. We have fabricated a light weight solar basket out of bamboo sticks. For this a parabolic curve of focal length 15 cm. was first drawn on paper and a mss rod was bent into this shape. Thin bamboo sticks of about 1 mm sq. and 5 feet long were woven into a basket of paraboloid shape. The help of a professional basket weaver was sought for this purpose. The bent mss rod was used to check the shape of the basket. The inner surface of the basket was rough. It was given a lining of a paste made of a mixture of wheat flour and fennugreek flour with water. The thickness of the paste layer was kept just sufficient to make the inner surface smooth. Metallised polyster paper (100 gauge) was then pasted on this surface with the help of an adhesive (fevicol). An iron rod pierced through the basket at the height of its focal plane serves to hold the basket on a stand. The cooking pot is placed on a ring welded to this rod in the focal area of the basket. The basket can be freely rotated in a vertical plane about this horizontal axis. Suitable cooking items can be cooked in about 100 minutes for a family of five during January to May in central India. The total cost of fabrication of 0.8 meter diameter solar basket is Rs.65 at Nagpur (India). Even at 50% collection efficiency it can give 400 W to the cooking pot.

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DEVELOPMENT OF A SOLAR HEATED DEHUMIDIFICATION SYSTEM
FOR GRAIN DRYING

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EXTENDED ABSTRACT

INTRODUCTION

In a developing country like India, wherein the agricultural operations are mostly monsoon oriented, a quick, reliable and economical drying system for its agricultural products such as paddy is a long felt need. As the harvest of the first crop in major areas of India coincides with the on-set of the second monsoon, there is a necessity for developing a solar heated drier adaptable for operation with auxiliary heat sources.

In an already warm and humid climate such as the one prevailing in tropical regions, usage of hot air for drying of grains has only a limited application. In the case of paddy, it has been found that temperatures in excess of 43°C reduces the germination quality and temperatures in excess of 60°C affect the milling quality. Besides the use of fossil fuels for heating the air might become uneconomical owing to the steep rise in the prices of these fuels. The conventional method of sun drying adopted in India at present leads to enormous wastage of food grains. Consequently, a necessity has arisen for resorting to the development of an alternate technology of drying by using dehumidified air.

EXPERIMENTAL SET-UP

The experimental set-up consists of a dehumidification system using a chemical absorbent, namely Calcium Chloride. Saturated solution of Calcium Chloride is continuously sprayed on a wooden matrix in the dehumidification chamber. The atmospheric air is passed through the chamber in a counterflow direction to the absorbent. The absorbent caused the dehumidification of the air and the dilution of the absorbent. The diluted absorbent was then passed through a heat exchanger where it

was heated by hot water flowing from flat plate solar collectors. The heated absorbent was then sprayed through a regeneration chamber identical to the dehumidifying chamber. Air was blown through this chamber in counter flow direction which causes the solution to be saturated and the saturated solution from this chamber was cooled and again sprayed into the dehumidification chamber.

EXPERIMENTAL RESULTS

Experiments were conducted for paddy depth of 15, 30, 45 and 60 cms. decrease in weight while drying with ambient air was first studied. These results were then compared with those obtained while drying with dehumidified air. The drying rates were then calculated and compared. It was observed that the rate of drying is very much faster with dehumidified air than ambient air.

Thermochemical Hydrogen Production
Kinetics of the Calcium Sulfate - Tungsten Oxide Reaction

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ABSTRACT

In a certain class or sub-set of thermochemical cycles, metal sulfates may be substituted for sulfuric acid as a means of overcoming the corrosion problems associated with the acid's use and cause an improvement in the cycle's overall efficiency as a decreased voltage may, in principle, be employed at lower acid concentrations that are permissible in the alternative metal sulfate system.

Calcium sulfate possesses too high an endothermic heat of decomposition and decomposes at too high a temperature (1807 K) for practical uses in a working thermochemical cycle. Reaction of calcium sulfate with tungsten oxide permits a reduction in the reaction temperature to ca. 1100 - 1200 K producing calcium tungstate and sulfur trioxide. The calcium tungstate can be recycled to calcium sulfate and tungsten oxide by sulfuric acid addition.

This study explored the kinetics of the calcium sulfate - tungsten oxide reaction with temperature and molar ratio of sulfate to oxide as the major experimental parameters. Runs were conducted at 1125, 1175, and 1225 K respectively at sulfate/oxide ratios of 2.0, 1.0, and 0.5. In general, the results showed reasonable (40 - 85) degrees of completion in times ranging from 10 min. to an hour, depending on the reaction conditions.

The results were modelled on the basis of a solid (CaSO_4) - gas (WO_3) reaction. Three rate-limiting cases : diffusion through product layer, reaction rate control, and diffusion through the gas film, were considered. At the lowest temperature, 1125 K, we found the reaction to be chemical reaction rate controlled. The results at 1175 K indicated a mixed mode

where both reaction rate and diffusion through the product layer played important roles. Finally, at the highest experimental temperature, 1225 K, it was found that diffusion through the product layer was the controlling mechanism. In all cases, the results showed the "best" correlation for a sulfate/oxide ratio of 0.5 (tungsten oxide, i.e., gas reactant in excess) as would be expected.

The study confirms that the mechanism of the reaction between calcium sulfate and tungsten oxide is indeed a gas - solid reaction and that maximum product yields are obtained at 1225 K (ca, 85%) at a sulfate/oxide ratio of 0.5 in 60 min. The reaction mechanism shifts from reaction rate control at 1125 K to diffusion through product layer control at the upper temperature, 1225 K.

This reaction may have utility as a sulfate sub-set of thermochemical hydrogen cycles provided the other reactions (lower temperature) in the cycle are verified.

EFFICIENT, TWO-REACTION SPLITTING OF HX ($X_2 = Cl_2, Br_2, I_2$)

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EXTENDED ABSTRACT

Discussion

Research groups worldwide are studying and/or developing water-splitting thermochemical cycles that incorporate decomposition of sulfuric acid as the oxygen-producing step. Several of the cycle concepts being studied sidestep the cycle-closing direct electrolysis of aqueous SO_2 to obtain H_2 by including intermediate reactions that produce either HBr or HI with H_2SO_4 . The efficiency of such cycles then depends upon the efficiency of that process used to close the cycle by splitting HBr or HI. Electrolysis of HBr[1] and pyrolysis of HI[2] are among the concepts being considered.

The splitting of HCl is of interest to that large and established part of the chemical process industry concerned with chlorination of hydrocarbons. The efficient recovery of H_2 and Cl_2 from by-product HCl is prized by that industry. Further, any such efficient process for splitting HCl can be coupled with the "reverse Deacon" reaction (or any multi-reaction equivalent) to complete a closed water-splitting cycle.

This paper presents a novel two-reaction process for obtaining H_2 and X_2 from HX. A higher temperature, endothermic reaction yields X_2 and reduced cation-loaded zeolite from reactants HX and oxidized cation-loaded zeolite. H_2 is then produced with a subsequent lower temperature exothermic reaction that also produces the oxidized cation-loaded zeolite suitable for recycling. Examples are given that compare calculations of thermal efficiency of this new concept with the thermal efficiencies of electrolysis of HCl[3] and HBr and pyrolysis of HI. The new concept is shown to be superior in several respects to the alternative methods and is far more efficient in use of process heat.

This research is an extension of and application of the results previously reported in [4].

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THE EFFECTIVENESS OF SOLID-SOLID HEAT EXCHANGE SYSTEMS USING AN INTERMEDIATE FLUID MEDIUM

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EXTENDED ABSTRACT

The Dorrance two-reaction thermochemical cycles [1] for the decomposition of water require quite efficient heat exchange between the hot, reacted, solids from the oxygen producing reactor and the cooler, reacted, solids from the hydrogen producing reactor. Direct heat exchange between two separate streams of particulate solids is mechanically complex and thermally inefficient, and therefore methods for heat exchange, using an intermediate fluid medium, have been investigated.

Two of the schemes that have been analyzed are shown in Figure 1. Figure 1-a shows a "conventional" regenerative heat exchange system of coupled countercurrent exchangers in two trains. For convenience in analysis, and for comparisons among alternative schemes, the heat exchange was presumed to take place in ideal stages, for each of which the exit fluid and solids temperatures were assumed to be the same.

An alternative scheme, shown in Figure 1-b, has the fraction 1/n of the total intermediate heat exchange fluid circulating only between adjacent ideal transfer stages in the two trains. The comparisons to be made include the number of stages required, and the amount of intermediate heat exchange fluid required, to attain the same overall heat exchange effectiveness.

The capacity coefficients for the solids streams, $\dot{m}_s C_{ps}$ (mass flow rate x heat capacity of solids) were taken to be the same for both trains, while the capacity coefficient for the intermediate exchange fluid, $\dot{m}_f C_{pf}$, was taken to be a fraction (or multiple) of that for the solids, viz:

$$\dot{m}_f C_{pf} = 8 \dot{m}_s C_{ps} \quad (1)$$

The overall heat exchange effectiveness, E, for equal capacity coefficients for the solids streams, is defined as

$$E = \frac{T_1 - T_3}{T_1 - T_2} \quad (2)$$

where the temperatures are as shown in Figure 1. This is the fraction of the maximum possible countercurrent heat exchange that could occur with a direct heat exchanger of infinite area.

The effectivenesses for the two schemes were derived and found to be:

$$\text{Scheme A.} \quad E_A = \frac{\beta(\beta^n - 1)}{\beta^n(2\beta - 1) - 1} \quad (3)$$

$$\text{Scheme B.} \quad E_B = \frac{\beta}{\left(\frac{n+1}{n}\right)\beta + 1} \quad (4)$$

These are compared in Figure 2. For the same number of ideal heat transfer stages, Scheme B is capable of reaching a slightly higher heat exchange effectiveness than Scheme A, but only at the cost of a very much greater intermediate heat exchange medium flow. The Dorrance two-reaction thermochemical cycles [1] already involve the circulation of considerable inert solid, along with the reactive species, between the high temperature and low temperature reactors; the circulation of vastly greater amounts of heat exchange medium would not be desirable.

Scheme A, therefore, need only employ a sufficient number of stages, preferably at $\beta = 1.0$, to attain a desired overall heat exchange effectiveness. For example, twenty ideal stages (in each train) are required to exceed 90% heat exchange effectiveness.

One possible implementation of Scheme A would be a pair of fluidized beds, either staged or not, with a countercurrent flow of gaseous intermediate heat transfer medium. Alternatively, moving beds of particulate reactive solids could be employed (similar to some regenerative gas-heating exchangers [3]). An actual design will depend upon mechanical considerations of solids transport and fluid circulation.

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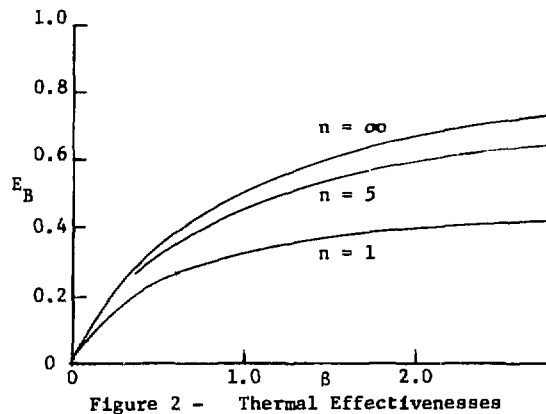
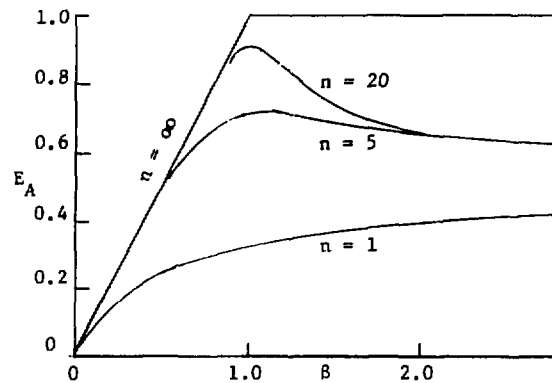
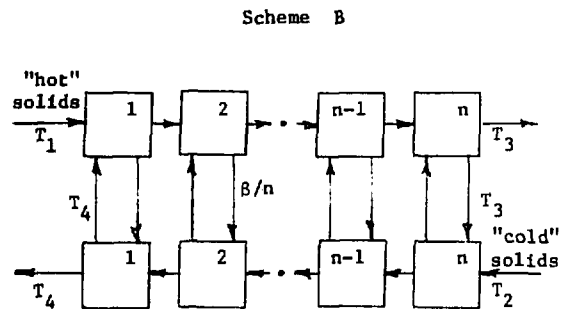
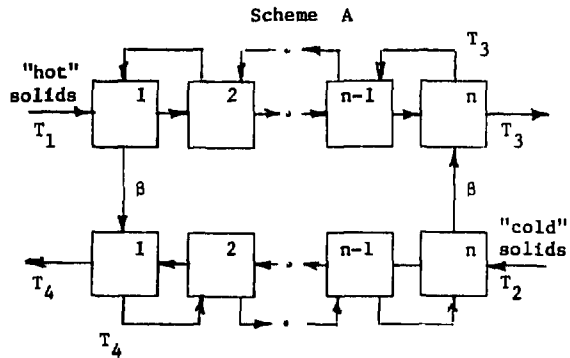


Figure 1 - Heat Exchange Systems

Figure 2 - Thermal Effectivenesses

The Environmental Impact of Thermochemical Processes for
Hydrogen Production - A Preliminary Assessment

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ABSTRACT:

Hydrogen production by thermochemical water-splitting is a technology still in its infancy. It therefore may be premature to discuss the environmental impact of conceptual plants involving specific thermochemical cycles to manufacture hydrogen on a large scale. Nevertheless, a preliminary assessment of this kind may well prove beneficial in guiding the future development of thermochemical cycles and aid in their selection.

The environmental impact for several current cycles was examined from a number of specific viewpoints: resource consumption, air quality, water quality, solid waste disposal, and accidental spills or leaks.

The assessment concludes that plants employing the thermochemical route for hydrogen production should be environmentally benign in normal operation as water and thermal energy are the major process inputs and hydrogen and oxygen and some reject heat are the major

plant products. Analysis of the specifics above indicate that these plants would show environmental impacts little different from those observed for an electrical generation plant employing the same heat source.

The most serious environmental impact would arise from any accidental spills or leaks that are impossible to quantify at this time. Estimates were made of the amounts of material lost to the individual process based on a specified recovery rate and a given plant capacity. For sulfur dioxide release, a 3000 MW_{th} plant would lose 30 tons/day at a recovery rate of 99.9%. This loss is well under the amount allowed by current air pollution laws of sulfur dioxide emissions from coal-fired electricity generation plants.

For other compounds that may be present in certain thermochemical cycles, i. e., mercury, cadmium, selenium, etc., the acceptable recovery rate will have to be set by prevailing environmental standards. The plants should be designed to minimize the possibility of accidental spills or leaks on both environmental and economic grounds.

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SESSION 2C

HYDROGEN ENERGY II

HARNESSING STORED GRAVITATIONAL POTENTIAL ENERGY AND CHEMICAL RAIN: HYDROGEN STORAGE-BIOMASS-SOLAR ENERGY SYSTEM: AGRICULTURE, BIOMASS, FOOD AND JOBS

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We here outline a long range system of relieving the arid and semi-arid areas of the world of three major problems: energy, food and jobs, in one stroke. This system relies on the 2300 year old principle of Archimedes, bouyancy, to deliver water to arid or semi-arid geographical areas in the form of gaseous hydrogen suitable for combustion, with by-products of hydroelectric energy, fuel cell energy, (perhaps) gas turbine energy, ocean minerals, ocean organic residue, industrial oxygen, elimination of the need for desalination plants and pump storage facilities, hot water, but most significantly large quantities of pure water suitable for irrigation and/or drinking to produce biomass (agricultural or animal) i.e. a new regional agribusiness producing large amounts of food and/or combustible biomass (for fuel, methanol, ethanol etc.) via creation of new jobs (planting, harvesting etc.) and significant government revenue tax base in heretofore undeveloped or underdeveloped arid and semi-arid geographical areas of the world.

A hydrogen economy is the ultimate goal of the recapture of wasted energy resources of the world. Basically any available extra energy should be chemically converted into hydrogen, for later combustion to reproduce the required electrical or heat energy. Hydrogen is clean, light, safe (with proper precautions-certainly safer than L.N.G. fuels) and adaptable to a variety of desired end uses, including as input to petrochemical processes as a feedstock. Hydrogen has one other trivial heretofore overlooked property: it is two thirds of each molecule of water: H_2O .

We reduce the problem of transport of water to arid areas to that of pumping hydrogen gas H_2 into those areas and then combusting the gas using atmospheric oxygen: $O_2 + H_2 \rightarrow H_2O$! How is this best accomplished?

Our system used three elements: earth, air, fire and water; certainly not newly discovered, polluting, high technology constructs nor discoveries! Hydrogen is the lightest element, with the lowest atomic weight; any other elemental or compound liquid or gas is heavier and will displace hydrogen to higher gravitational potentials when mixed with hydrogen. The components of the earths environment are arranged in order of decreasing density vertically: Fe core, silicate rock, liquid water- H_2O , gaseous air- N_2O_2 etc., and were it to exist freely, hydrogen- H_2 . So three quarters of the earths surface is covered with H_2O molecules two thirds of which are composed of the lightest element, H_2 . Hydrogen is trapped far below its equilibrium

gravitational potential in the form of being bound up in liquid H_2O . We here propose a system which is merely a chemical form of rain i.e. making rain in a tube. This system is open port, accepting any input energy resource otherwise wasted (excess nuclear plant capacity at night, burning biomass, burning garbage, solar photovoltaic (for H_2O electrolysis), solar thermal (for catalyzed photolysis) etc.) No special input is preferred, all can be used interchangeable depending upon the particular economic and geographical requirements and strategies at a given time in a given place. The system is retrofittable, new devices being introducable as their efficiency is improved in time or new technology is developed. The system is adaptable to batch or continuous operation. The system is ecologically and environmentally sound and nonpolluting. The system can be used flexibly to produce not only electrical energy and water, but hydrogen as petrochemical plant input feedstock, or as fuel for autos or airplanes (when such engine technology arrives technologically or economically). (FIRE & WATER): Basically H_2 is produced at the seacoast by an available energy source (solar catalyzed direct photolysis of H_2O preferred, if ever feasible), with saleable by-products of inorganic mineral sludge, organic residue (ocean foods and input to pharmaceutical processes for vitamins etc.). The H_2 is put into the bottom of a pipe; into the top is introduced air, or for safety N_2+CO_2 -factory exhaust gases from a factory at the higher gravitational potential. Preventing turbulent mixing of the H_2 with the heavier, denser working fluid gases allows Archimedes' principle of buoyancy to work unimpeded, with perhaps some energy extraction if a suitable gas turbine can be economically designed and run. At the top of the mountain, (the higher gravitational potential) the H_2 is extracted and either stored in FeTi hydride beds of large capacity (batch mode) or continuously combusted in a fuel cell (continuous mode). The by products are fuel cell generated electrical energy and most important hot distilled, pure water at a higher gravitational potential (EARTH). It is now sent back down to its equilibrium gravitational potential level in the molecular form of H_2O : on the way one extracts electrical energy via a hydroelectric turbine² system or a newly constructed system. But there is no need to return it to the sea; via the water table, or evaporation or river system it returns- the seas are never depleted. Rather one should send this by product water to the semi-arid or arid areas where it is more prized than electrical energy: for human drinking, animal consumption, industrial feedwater and most important, irrigation feedwater to produce (after suitable soil preparation and planting) large quantities of biomass (food and timber and synfuel -methanol and ethanol via production of eucalyptus or sugar cane or corn or grains or soy beans etc.). The by products of this newfound ability to irrigate and produce agribusiness in heretofore undeveloped or underdeveloped desert or high plateau areas, are increased agribusiness employment (jobs to plant, harvest, convert and transport this new biomass) providing a large new agribusiness government tax base in nonproducing geographical areas. Thus this retrofittable, versatile, open energy input system utilizing the three ecologically and environmentally sound Greek elements of EARTH, AIR, FIRE (hopefully solar) and WATER (working fluid and byproduct) is actually a limitless form of harnessing rain and trapped energy of gravitation.

INTERFACING CONCENTRATED SOLAR RADIATION AND HIGH
TEMPERATURE HYDROGEN PRODUCTION PROCESSES

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EXTENDED ABSTRACT

INTRODUCTION

The two and three-step thermochemical cycles and direct decomposition of water have been found more attractive than the others due to lower separation and recycling work and higher theoretical overall efficiency. They require however one or two high temperature reactions which may have a level above 1400 K. This level is too high for nuclear reactors but corresponds to the possibilities of the solar concentrators. The major problem is to interface concentrated solar radiation and high temperature reactions. For this it is necessary to study and design an efficient radiation receiver which could also be served as a reactor. Therefore, it is desirable to carry out both theoretical and experimental heat transfer studies with different configurations and materials.

CONCENTRATED RADIATION RECEIVERS AND THERMOCHEMICAL REACTORS

Many types of concentrated radiation receivers have been studied in the past. The cavity type receiver is approaching black body form and its efficiency is high. Receivers of this type made with refractory metal tubes have been studied theoretically and experimentally. With platinum and tantalum Le Grives et al. and Le Phat Vinh obtained efficiencies in the order of 50% at about 1600 K to heat an inert gas. For the thermoelectric solar power plants, commercially available refractory metals such as Inconel have been tested at an operating temperature of about 1000 K. Even without reaction the problem of compatibility exists between receiver material and fluid. Over 1200 K, ceramics seem to be the only materials available and few results are available in the literature. An important problem with the ceramic receivers is the creation of a watertight circuit.

PRESENT STUDY

In this study, a cylindrical cavity is used as a receiver for concentrated solar radiation coming from a parabolic mirror. A mathematical model has been developed to simulate the incoming radiation from the sun with double reflection, once on the heliostat and then on the parabolic concentrator. The heat flux and temperature distributions are then calculated in the cylindrical cavity for a uniform and non-uniform radiation distribution at the entrance of the cavity, axial and radial conduction are considered but convection has been neglected. This case corresponds to operation mode of reactors under controlled atmosphere. For the radiation calculation, the surfaces are assumed to be gray and diffuse surfaces and the non-isothermal condition is modelled.

GAS EVOLUTION DURING WATER ELECTROLYSIS: GAS BUBBLE
BEHAVIOUR, GAS FRACTION AND ELECTROLYTE RESISTANCE

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EXTENDED ABSTRACT

INTRODUCTION

Gas bubble evolution during water electrolysis has been studied for the purpose of understanding the mechanism of the effect of the gas bubbles on both mass transport and energetic efficiency, hence trying to reduce the energy losses caused by the gas bubbles. Another problem occurring during water electrolysis, due to the very small sizes of the hydrogen and oxygen bubbles, is the phase separation. In order to contribute to a solution of this problem, data on the size and distribution of the gas bubbles after their departure from the electrode are necessary.

GAS BUBBLE BEHAVIOUR AT NATURAL CONVECTION

The extremely slow growth of electrolytically generated gas bubbles is mass diffusion controlled. In general, bubbles, generated at an electrode behave similarly to free bubbles, i.e. the bubble radius is proportional to the square root of time. Theoretically, a relation has been derived for the radius, R , of a bubble, tangent to the wall, in an initially uniformly supersaturated liquid with supersaturation, ΔC , in the absence of any convection [1, 2]:

$$R = \left\{ \left(\frac{3}{\pi} \right)^{\frac{1}{2}} Ja + \left(\frac{3}{\pi} Ja + 2 \ln 2 \cdot Ja \right)^{\frac{1}{2}} \right\} (Dt)^{\frac{1}{2}}$$

with: $Ja = \Delta C / \rho_g =$ Jacob number, $\rho_g =$ gas density, $D =$ diffusion coefficient and $t =$ time.

The nucleation and the gas bubble behaviour at the electrode is, similarly to nucleation and vapour bubble behaviour during boiling, affected by the nature of the electrode, respectively heating wall, and the electrolysis time (cf. fig. 1), respectively boiling time.

Hydrogen and oxygen bubbles are investigated with transparent electrodes, the oxygen bubbles up to a pressure of 750 kPa in a 30 wt% KOH - solution. Both the oxygen bubble population and the oxygen bubble departure radius increase at increasing current density and at increasing KOH - concentration. The bubble population increases also at increasing pressure.

A theoretical model has been derived for the effect of the gas bubbles on the mass transport at the electrode. This model is related to Van Stralen's "relaxation microlayer"-theory for the mechanism of nucleate boiling. Some experimental results are compared with theoretical predictions.

GAS FRACTION AT NATURAL CONVECTION

According to the impedance method, the electrical resistance of the electrolyte surrounding a horizontal circular electrode, generating gas bubbles, has been measured in dependence of the following parameters: current density, electrode diameter, pressure, temperature and KOH-concentration. Both for hydrogen and oxygen, the gas fraction at the electrode depends on the KOH-concentration and increases at increasing current density, (cf. fig. 2) at decreasing pressure and temperature and at increasing gas volume flux. In general, at constant gas volume flux, the gas fraction at the electrode increases at decreasing pressure. The value of the gas fraction for oxygen exceeds the corresponding value for hydrogen.

ELECTROLYTE RESISTANCE

The potential drop has been measured between two opposite luggin capillaries (of which one is located near the diaphragm and the opposite one behind the working gauze electrode) and between a capillary near the diaphragm and the opposite working electrode (with the interruptormethod). The experiments have been carried out with a cell, containing electrodes of $500 \times 20 \text{ mm}^2$ in a 30 wt% KOH-solution at atmospheric pressure at five different heights, with and without a back chamber behind the working electrode. Also the distribution of the local current density has been determined, using flat segmented electrodes. For both types of electrodes, the current density, flow velocity and height are used as parameter. Both for hydrogen and oxygen, the most important results are the following:

- (i) the bubbles in close proximity to the electrode contribute substantially to the potential drop. This behaviour is similar to that at natural convection;
- (ii) an increase in the flow velocity causes a decrease in the potential drop; the contribution of the gas bubbles in the bulk electrolyte increases at increasing gas fraction; cf. fig. 3
- (iii) the current density decreases at increasing height, cf. fig. 4.

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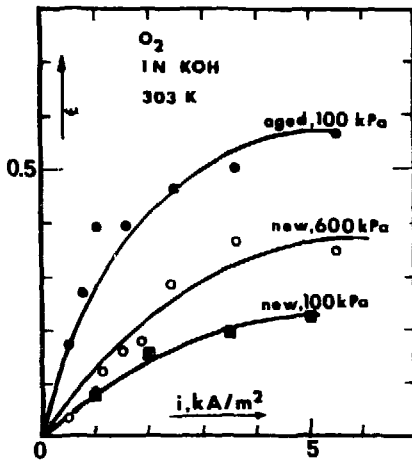


Fig. 1. Gas volume fraction, ϵ , at the electrode as a function of current density, i , obtained with two new and one aged horizontal, transparent, nickel electrodes by taking pictures.

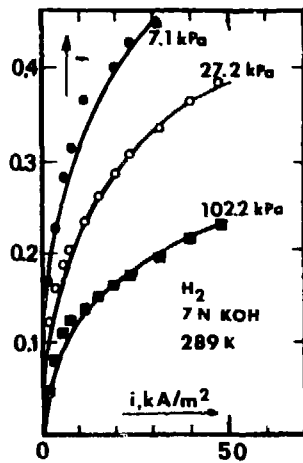


Fig. 2. Gas volume fraction, f , versus current density, i , obtained with a horizontal, nickel electrode with a diameter of 1.0 mm.

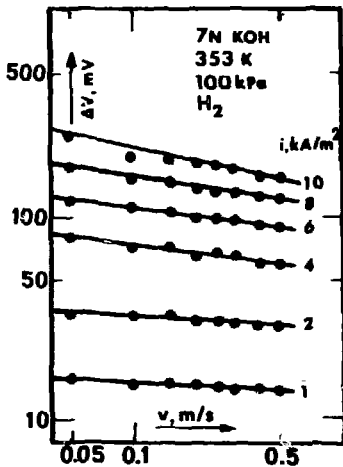


Fig. 3. The potential drop, ΔV , between two opposite luggin capillaries versus the flow velocity, v , in the middle of a vertical cell (height 0.5m).

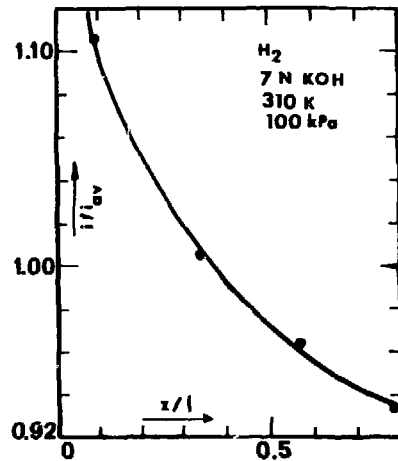


Fig. 4. Current density, i/i_{av} (i_{av} =average current density) versus the dimensionless height, z/l (l = length of the electrode) at a gas volume fraction of 0.4 in the top of the cell, obtained with four electrode segments.

LAMINAR BURNING VELOCITIES OF HYDROGEN/OXYGEN/INERT GAS MIXTURES

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EXTENDED ABSTRACT

INTRODUCTION

Burning velocity of flammable mixture with hydrogen is of great contemporary interest, as one of the fundamental combustion characteristics, in connection with safely controlled utilization of hydrogen as an alternative clean energy source. Hydrogen flames premixed with an oxidizer have a flash-back tendency due to high burning velocity. To avoid the flash-back hazards, diffusion flames are frequently used in practical combustion systems. Laminar burning velocity of flammable mixtures is an useful parameter for correlations in a variety of combustion phenomena even in diffusion flames, for example, as concluded in the previous work by the authors [1].

Hydrogen will possibly be used, as a tentative measure in a transition period until a complete hydrogen energy system is achieved, mixed with gaseous hydrocarbons such as natural gas or inert gases because of its highly reactive nature. Despite a great deal of literature are available on hydrogen-air combustion properties [2], knowledge of the burning velocities of these hydrogen mixed fuels is extremely limited.

In the present investigation, the emphasis was laid on the effects of inert gases on the laminar burning velocity of hydrogen flames. The replacement of one kinetically inert gas for another in a flammable mixture will make the simplest changes in the thermal and transport properties of the mixture. Nitrogen in air was replaced in turn by argon and helium. Oxygen mole fraction in oxygen-inert gas mixture and the equivalence ratio were employed as experimental variables.

EXPERIMENTAL

The nozzle burner/schlieren cone angle method, which is considered preferable among the stationary flame methods [3], was employed. The burner system consisted of a nozzle head fitted to a sufficiently long pipe of 41 mm inner diameter to produce a laminar flow. The nozzle diameters were 7 mm and 10 mm. Hot wire anemometry measurement, using an air flow, confirmed that the velocity profile at the nozzle exit was uniform except a peripheral region in which the effect of wall boundary layer existed. Unburned gas velocity inside the flame cone was determined by laser Doppler velocimetry (LDV), which was applied to the burning velocity measurements recently [4].

A He-Ne laser of 5 mW and a counter type signal processor were used. Fine alumina particle of 1 μ m diameter was employed as a tracer for the LDV measurement. The flame cone angle was measured from a spark schlieren photograph using a film analyzer. Thus the laminar burning velocity, S_u , is given by the equation

$$S_u = U_u \sin(\gamma/2),$$

where U_u is the unburned gas velocity and γ is the schlieren cone angle. The oxygen mole fraction in the oxygen-inert gas mixture, X_{OA} , was set at 0.21, 0.15, and 0.09, and then the equivalence ratio, ϕ , was varied between 0.9 and 4.0, for each inert gas system.

RESULTS

The results obtained using nitrogen as a diluent are shown in Fig. 1. Although there were a number of data on the laminar burning velocity of hydrogen-air system, the other data presented in this study were not available previously, except in fragmentary form. The laminar burning velocity of hydrogen-air mixture, i.e., $X_{OA}=0.21$, were obtained in reasonable agreement with the data of previous workers [2, 3]. The maximum burning velocity of hydrogen-air mixture was 3.1 m/s determined at ϕ of 1.8, and it decreased linearly with reducing X_{OA} at the same value of ϕ .

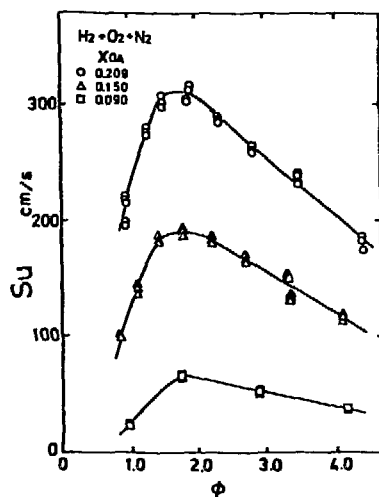


Fig. 1. Laminar burning velocities of hydrogen/oxygen/nitrogen mixtures.

Under a certain condition of X_{OA} and ϕ , the laminar burning velocity was the highest when helium was used as an inert diluent, followed by argon and nitrogen in turn. The maximum burning velocities under constant X_{OA} conditions were recognized at ϕ of 1.8-1.9 in all cases of X_{OA} and inert gases. The variations of the maximum burning velocity with X_{OA} were substantially linear for every inert gas system.

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"The Impact of Substituting Fuel Cells for
Internal Combustion Engines in H₂-Fueled Automotive Vehicles"

by

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ABSTRACT

H₂ fuel-cells have much higher energy-conversion efficiencies than H₂-fueled internal combustion engines. Therefore, substitution of fuel-cells for internal combustion (I.C.) engines could result in major improvements in the performance of H₂-fueled automotive vehicles.

The proposed paper will present the results of a study that quantified the magnitude of the decrease in vehicle mass and vehicle energy consumption expected from the substitution. The methodology employed in the study was developed and described elsewhere, and was used previously to compare the performance of H₂-fueled I.C.-engine vehicles with that of electric vehicles employing secondary batteries.

Comparisons between fuel-cell and I.C.-engine vehicle total (laden) mass and energy consumption will be presented for both urban and highway missions.

HYDROGEN FUELED SHIPS

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EXTENDED ABSTRACT

INTRODUCTION

The early warnings and the start of the present energy crisis are briefly reviewed in order to present a background for the discussion of hydrogen as a transportation fuel. The studies on the different areas of the transportation industry which could use hydrogen fuel are touched upon and the Navy studies on hydrogen fueled ships are reviewed. The purpose of the paper is to review and critique the previous Navy studies, particularly those which have not been reported in the literature, and to extend the results of those studies to commercial ships.

REVIEW OF THE U.S. NAVY STUDIES

A brief review of the particular concerns of the Navy with regard to future fuel supplies is given. The concerns of increased cost and decreased supplies of high quality fuel caused the Navy to undertake several studies as to the potential of alternate fuels and particularly hydrogen. A summary of each of the Navy studies is presented, highlighting the important results with respect to the impact of hydrogen on ship design and performance. The review process is divided into four sections, each section covering the studies performed by a particular agency or company.

Naval Research Laboratory Reference 1 compared hydrogen with other oil and non-oil based alternative for both military ships and shipboard aircraft.

Naval Research and Development Center Reference 2 presents a compendium on the hazards of using hydrogen as a military fuel.

Stevens Institute of Technology Three reports were published 3, 4, and 5 over a two year period. The first report discussed hydrogen production, transmission by pipeline, and utilization in spark ignition engines. The second report discussed the problems associated with the transfer and storage of liquid hydrogen. The final report discussed the problem of various reciprocating and gas turbine engines.

GE-TEMPO Division The two studies performed by GE-TEMPO 6 7 assessed the impact of hydrogen fuel on Navy mission performance and cost. The first study compared the performance of several combatants using a

variety of alternate fuels. The second study compared the performance of conventionally supplied, diesel fueled ships with hydrogen fuelled ships supplied by nuclear powered factory ships.

EVALUATION OF THE RESULTS

This section presents a confirmation of those results which are valid and an explanation of those results which appear to be incorrect. Where possible, revised methods of analysis are proposed and an indication of the probable effect is given.

HYDROGEN FUELED COMMERCIAL SHIPS

The important differences between naval and commercial ships are explained and the results of the Navy studies are extended to commercial ships. The effect of hydrogen fuel on various ship types are explained.

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LIQUID HYDROGEN STORAGE AND REFUELING FOR AUTOMOTIVE APPLICATIONS¹

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EXTENDED ABSTRACT

The Division of Transportation Energy Conservation of the U.S. Department of Energy, the Los Alamos Scientific Laboratory, the Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (DFVLR), and the New Mexico Energy Institute are participating in a cooperative project to examine the use of liquid hydrogen as an automotive fuel by investigating the liquid hydrogen refueling process, assessing safety problems in this



Fig. 1. 1979 Buick Century converted to operation on liquid hydrogen.

¹This work done under the auspices of the United States Department of Energy.

application of liquid hydrogen fueled vehicles, and demonstrating the state-of-the-art in liquid hydrogen fueled vehicles.

A 1979 Buick Century with a 3.8-L displacement turbocharged V-6 engine (see Fig. 1) has been converted to operation on hydrogen which is supplied to the engine from a 150-L aluminum on-board liquid hydrogen storage tank designed and built by the DFVLR (see Fig. 2). Although this tank has performed satisfactorily, a new tank is being jointly built by the LASL and the DFVLR. The new tank will be cylindrical in shape with a stainless steel inner vessel and an aluminum outer vessel with two copper radiation shields cooled by boiloff hydrogen gas. To eliminate the venting of hydrogen under normal conditions we propose to use the boiloff hydrogen gas to operate a fuel cell which will supplement the alternator or generator normally driven by the car engine.

The car is being routinely refueled with liquid hydrogen using a refueling station that was designed and built by the DFVLR. The liquid hydrogen transfer process has been examined and the major mechanisms investigated account for about 2/3 of the measured losses. Liquid hydrogen losses such as boiloff are not too difficult to determine; however, operating losses, such as occur during refueling, are more nebulous. Transfer losses involve the mass of metal to be cooled down, heat leak through the thermal insulation, cooldown of the pressurization gas, and flashing. Some of these losses depend upon the flowrate and some depend upon the temperature of the transfer lines and the on-board storage tank; therefore, the operating procedure becomes an important factor in minimizing these losses.



Fig. 2. DFVLR Dewar installed in trunk of the Buick.

EXPERIMENTAL STUDIES ON MICROCAVITY HYDROGEN STORAGE

by

Robert J. Teitel*

A new approach to hydrogen storage was introduced recently and reported last year. The microcavity storage concept employs hollow glass microspheres (nominally 6-220 μm diameter with .5 to 5 μm wall thickness) to contain high pressure hydrogen. Filling and removal of hydrogen is accomplished at slightly elevated temperatures by permeation through the thin glass walls. In 1978, an engineering study on an automotive application of the microcavity system was performed. The microcavity system was compared to an advanced metal hydride storage system $[(\text{Mg}_x)\text{H}_2-(\text{Fe,Ti})\text{H}_2]$ to meet the same requirements. The results indicated that the microcavity system promises to be lighter and less expensive than the hydride system. However, it will occupy a larger volume.

This paper will discuss the first experimental studies to find hollow glass microspheres to fulfill the automotive application requirements. The search was limited to commercially available microspheres, and narrowed to two that appeared most promising, based on vendor information. A 3M grade D32/4500 was selected for its high reported crush strength, and Filiite grade 200/.7, for its low cost. Representative samples of the two grades were characterized by determining their particle size, chemical composition, crush strength, etc.. Flow of hydrogen into and out of microspheres was studied on small bed samples (1-5cc).

In this study, the microsphere grades were first tested in their "as received" condition. In addition, an exploratory study of the effect of physical (sieving) and thermal treatments on the bed characteristics was conducted.

Specimens were filled under conditions to minimize breakage, and the hydrogen withdrawn at rates above that required for automotive propulsion (.7ccm/cc of bed) as determined in previous engineering studies. Microsphere breakage at various fill pressures were determined. The available hydrogen from the filled microsphere bed at temperatures up to 250°C were also determined. This characteristic was evaluated by measuring the fraction of the total H_2 volume available at the assumed maximum operating temperature.

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Principal conclusions of the study were as follows:

3 M Grade D32/4500

This grade came closest to fulfilling most of the requirements set forth in the previous engineering study for the automotive application. The most important storage characteristics attained are:

Wt density of Stored H_2 - .053 to .063 gm H_2 /gm bed
Volume Density of Stored H_2 - .012 to .015 gm H_2 /cc bed
Fill pressure - 35000 - to 4000 psi
Available H_2 at 200 and 250°C respectively-55 and 70%
Storage Half Life - ~110 da.

Fillite - 200/7

This grade did not perform well for the automotive application. The wt. density of H_2 was low and the availability of H_2 was low.

Details of these studies will be presented.

A RARE EARTH METAL HYDRIDE DEVICE FOR
MINIMIZING LABORATORY HYDROGEN HAZARDS

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A major application today for the use of hydrogen is with medical and industrial laboratory instrumentation and equipment. Such devices as gas chromatographs, atomic absorptiometers, sulphur analyzers, etc., utilize hydrogen gas in the processing of samples. Many of these instruments are found in hospitals, university laboratories and law enforcement laboratories. Because of the extensive energy content of compressed hydrogen gas, safety considerations are of paramount interest to these groups. For this reason, the safe storage and dispensing of hydrogen has been of concern to them for many years.

A compact, portable, and ultra-safe storage unit for hydrogen has been developed by the Laboratory Data Control Division of Milton Roy Company. The device, named H₂YCELL, employs encapsulated LaNi₅ metal hydride housed in a rugged canister. Up to 8 cubic feet (226 cubic meters) of hydrogen can be stored in this device. The operation of the unit has been simplified so that entry-level lab technicians will have no difficulty in safely using the H₂YCELL.

The initial design of the H₂YCELL unit is intended to replace the "lecture bottle" class of hydrogen cylinders. Since the flow requirement of most instrumental systems utilizing hydrogen is on the order of 100mL/min (6L/hr), the H₂YCELL unit should provide over 35 continuous hours of operation for most applications. Often, several instruments are run in parallel from the same source of supply hydrogen. LDC decided, therefore, to strive for a flow rate of at least 15 to 20 liters per hour in the initial design. Thus, about 8 to 10 continuous hours of operation can be provided when three or four typical instruments are simultaneously supplied hydrogen from the H₂YCELL.

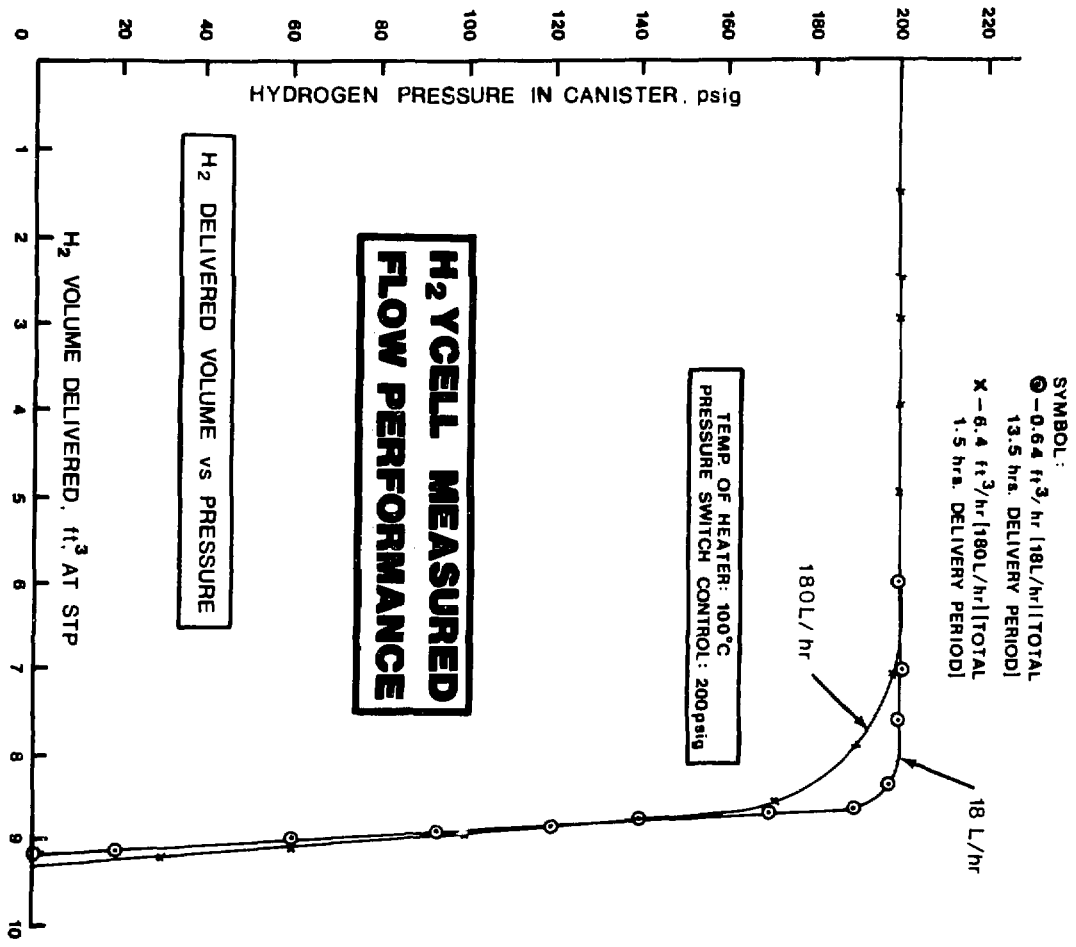
Hydrogen is stored in the H₂YCELL at densities greater than that of liquid hydrogen, despite the room temperature and low pressure (25psi at 75°F) conditions that are present when used. The 8 cubic feet (226 liters) of hydrogen remain "locked-up" in the hydride, with the exception of about one liter which remains as gaseous hydrogen in the unused volume

of the canister. Van't Hoff diagrams show that increased temperature of the hydride increases the equilibrium pressure of the hydrogen. The result is an increased desorption of hydrogen as the metal hydride is heated. For example, the application of heat sufficient to raise the equilibrium pressure to 200 psig increases the desorption rate, producing flows of up to 180 liters per hour. The figure illustrates the measured flow performance of the H₂YCELL at 18 and 180 L/hr, 200 psig.

One outstanding advantage of this metal hydride storage unit is the high purity of hydrogen which it supplies. Since the metal hydride is specific in the absorption of hydrogen only, the hydrogen supplied by H₂YCELL is ultra-pure. Relatively impure hydrogen from sources such as cylinders is automatically purified when used to charge the H₂YCELL. Only hydrogen is retained by the metal hydride. All of the impurity gases are stored in the "dead volume" of the canister. These impure gases can be bled off prior to utilization of the H₂YCELL. Atomic absorption data reveals hydrogen impurities of less than 50 ppb after bleeding off the first 5 to 10 liters of this H₂YCELL output gas. Ultra-pure hydrogen from electrolytic hydrogen generators can also be used to recharge the H₂YCELL, although longer periods are required because of the lower pressures and flow rates involved.

H₂YCELL has one very unique advantage over hydrogen cylinders and other metal hydride storage systems not applying rare earth materials. The rare earth metal hydride releases the hydrogen at a nearly constant pressure over a very extensive range of its total capacity, as the Figure reveals. Thus, for many applications, a regulator valve is not needed.

The upper limit of flow at 180 liters per hour suggests applications where small scale energy systems are involved. For example, a small hydrogen torch could be powered by the H₂YCELL at maximum flow. The total energy content of the H₂YCELL at 180 L/hr represents approximately 0.7 horsepower, assuming 100% energy conversion.



PERSPECTIVE OF BIOMASS AS AN ENERGY SOURCE
IN THE DOMINICAN REPUBLIC

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EXTENDED ABSTRACT

INTRODUCTION

Biomass contributes approximately 30% to the supply of primary energy in the Dominican Republic. In 1978 this contribution was equivalent to 6.94 million barrels of oil (see Table No. 1) [1]. We believe this percentage has been diminishing continuously over the last two decades due to the rapid growth of oil consumption during the same period. Recent studies showed biomass can play an important role in the Dominican Republic as a source of renewable energy.

TABLE NO. 1
ENERGY SUPPLY FROM PRIMARY SOURCES IN THE DOMINICAN REPUBLIC

In thousands of equivalent oil barrels
(10³ boe)

Resource	1977	%	1978	%
Oil and oil subproducts	14,670.4	68.02	14,503.9	67.12
Hydroelectricity	105	0.49	171	0.79
Bagasse	4,079	18.91	4,143	19.17
Wood	2,440	11.31	2,513	11.63
Charcoal	273	2.27	282	1.30
TOTAL	21,567.4	100.0	21,612.9	100.0

Source: Acosta, J.R., 1980, "Oferta y Demanda de Energía en la República Dominicana: Características y Perspectivas"

BIOMASS ENERGY PRODUCTION

Sugar cane plant is the most important renewable source of biomass in the

Dominican Republic. The sugar cane bagasse is burned in specially constructed furnaces at the sugar mills to generate steam process and electricity. Sugar cane bagasse satisfy 82% of energy demand of the sugar industry in Dominican Republic.

Besides this, firewood and charcoal are extensively used at rural and urban household and in small industries. Due to previously high rates of deforestation, the government has established restrictions on logging. The current estimate of wood production for firewood and charcoal is 17.27 quadrillion Btus (10^{12} Btus) annually, of which about 90% is for firewood [2] .

BIOMASS ENERGY POTENTIAL

According to recent studies prepared for the Comisión Nacional de Política Energética, biomass energy can help not only to reduce oil dependence and its negative pressure on balance of trade, but also provide rural employment opportunities and possible utilization of large extensions of marginal lands.

One promising possibility for increasing wood production is tree farming. The Dominican Republic has about 1.3 million acres of arid and semi-arid lands available for biomass farming. This land represents a total potential of 200 MWe to 1,400 MWe of installed electrical capacity, based on biomass yield estimate used for these unirrigated dry forests [3] .

In 1978 sugar cane bagasse contributed an estimated 4,143 Kboe to the energy supply of the country and by the year 2,000 the contribution is expected to nearly double, mainly because of solar drying bagasse presently under research and improvement in thermal efficiency at the sugar mills.

The potential of a number of agricultural residues from different crops such as cotton, beans, corn, etc. has been estimated in 1.6 quadrillion Btus (1.6×10^{12} Btus) annually, and from agroindustrial wastes in 3.2 quadrillion [4] . The installation of a 3 MW thermal power station to burn rice husk is presently under consideration.

The Comisión Nacional de Política Energética is devoting special attention to biogas production. Several digestors have been constructed by this governmental agency in collaboration with agricultural schools with the intention of accelerating the process of disseminating the technology.

PERSPECTIVE

Current research and development projects in the Dominican Republic assure a rapid growth in the participation of biomass in the future energy supply and demand picture of the country.

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SESSION 4C

BIOCONVERSION II

CONSTRAINTS TO BIO-ENERGY DEVELOPMENT

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EXTENDED ABSTRACT

For more than a decade the United States has been facing an uncertain energy future. Because of this problem, the country continues to be saddled with a balance-of-payments deficit, the need for increased importation of foreign oil, and a vulnerability to sudden disruptions in the petroleum supply. The dilemma has encouraged research into and development of domestic energy alternatives that are renewable, cost-effective, and publicly acceptable. Among the alternatives being considered are the bioconversion technologies that are designed to convert various kinds of biomass into energy sources. To date bio-energy research has focused on the mechanics of the bioconversion processes and assessments of resulting environmental impacts. However, there are other obstacles to overcome before biomass can be converted to more useful forms of energy that fill existing needs. These constraints include social issues, technology adaptation, governmental regulations, and economic problems, considered separately or as they interact with each other.

Social deterrents can be diverse and powerful enough to prevent the deployment of a technology: witness the public's negative attitude toward the use of nuclear power [1]. In the case of bio-energy, many people perceive this technology as a wasteful "burning of food," because the biomass may be a substance normally used for human food or animal fodder. Another deterrent is inadequate information transfer. Misinformation about new technologies, inaccessibility of commercially available tools, and a generally suspicious attitude toward the new and untried tend to inhibit development activity on the part of those involved in agriculture.

Industry's attitudes can also be an inhibition. For example, although rural electrification co-operatives are likely to benefit from small, decentralized bio-energy facilities, they have been slow to accept the challenge [2]. Also, oil company representatives have presented adverse testimony on the hazards of on-farm ethanol production [3]. There is also the problem of adapting technologies to bioconversion. The farming infrastructure in each region of the US has come about through an evolution of management practices. Machinery designs and orientation of activities are chosen to support an existing market. Because the biomass usually originates on the nation's farms, the

farmer must adapt agricultural practices to fit energy development technologies. This adaptation most likely will occur when it dovetails with existing farming activities.

Governments have been given the right to regulate and control local development through zoning and the permitting processes. Implementation is subject to the local government attitude toward the interpretation of general welfare, which has proven to be very broad [4]. Where attainment of renewable energy at the local level may be in the best interest of the community welfare, the law has been interpreted to protect aesthetics and character of a community [5]. Local attitude could effect facility siting.

In addition to states' power, the Federal Government has power to regulate interstate commerce, which has been interpreted to mean any transport of material across state lines, including pollutants [6]. Where neither a product nor its resulting pollution cross state lines, the states are responsible for enforcement. Many of the emerging biomass energy systems will be regulated by the Environmental Protection Agency.

Economics plays a part in energy development. Farmers may encounter increased expenses for pollution control technologies, facility siting, transportation of residues, and land improvements. The cost of converting crop residues to fuel includes the direct costs of harvesting, transportation, and processing and possible indirect losses attributable to soil nutrient depletion and cropping shifts. In addition, although there is considerable acreage in the South that is available for sugar cane production, the cane-to-ethanol process is not economically competitive with other energy sources because it is labor-intensive and highly technical [7]. Thus, the US imports ethanol from Brazil, where labor is cheap, and could again become dependent on another foreign fuel source [8].

In conclusion, bio-energy potential is promising and conversion technology is available. But there is a problem in matching existing energy needs with this potential, and there are many constraints to development. One could say that the US is experiencing an implementation crisis, not an energy crisis. Although biomass resources exist at the local level, development activity will be minor until constraints are mitigated. Because bioconversion activity will be dispersed, it will not contribute significantly to the reduction of dependence on foreign energy sources, and both positive and negative impacts will be minimal.

However, if the agricultural sector successfully initiates local information transfer, and the USDA achieves its dynamic goal of energy self-sufficiency by year 1990, the situation could change. Once the problems of legal, socioeconomic, and technological constraints are solved, bioconversion could contribute significantly to local energy supplies.

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ABSTRACT

ACID HYDROLYSIS OF CELLULOSE

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One of the alternatives for increasing the production of ethanol is by the hydrolysis of cellulose content of agricultural wastes. Studies have been made on two types of hydrolysis: enzymatic and acid. Data obtained from the sulphuric acid hydrolysis of cellulose showed the process to proceed in two stages, with a yield of approximately 95% glucose. Because of increases in cost of alternative resources, the high demand of the product and the more economic production of ethanol from cellulose materials, it is certain that this technology will be implemented in the future. At the same time further studies on the disposal and reuse of the byproducts of this production must be undertaken.

The Potential For Using Sweet Sorghum as a Feedstock for
the Production of Fermentation Ethanol

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The need to supplement fossil resources with renewable resources for the production of fuels and chemicals is now well established. The major issues concern the choice of renewable resources, the desirable end product, and the processing and conversion technology to refine a feedstock to a useful end product. Sweet sorghums (Sorghum bicolor L. Moench) offer considerable potential as a broad spectrum energy crop based on the following characteristics: (1) they produce high yields of simple carbohydrates, (2) the stalk residue has considerable potential as a fuel and/or chemical feedstock in itself, (3) the germplasm available for use is large and highly adaptable, and (4) generally speaking, sorghum is drought tolerant and efficient in nutrient use which lowers production input costs without sacrifices in yield.

Sweet sorghum and its relatives are among the least exploited agronomic crops. Therefore, at this time, the sweet sorghums can best be described as "viable" biomass candidates. Problems remain to be solved before the sweet sorghums are commercially cultivated for fuel or chemical production. Among the problems which require further research are: (1) harvesting, (2) stillage disposal, (3) refinements in commercial agronomic situations, and (4) reduction of fixed processing and conversion costs.

The objectives of this presentation are to highlight previous research and future directions of sweet sorghum development and to give perspective to the role which sweet sorghum may play in the United States' biomass energy program.

POTENTIAL OF ENERGY FARMS IN THE
DOMINICAN REPUBLIC

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EXTENDED ABSTRACT

This paper contains a preliminary assessment of the potential of generating electricity from biomass fuels produced on lands considered marginal for agriculture production in the Dominican Republic.

The Dominican Republic occupies the eastern two-thirds of the island of Hispaniola in the Caribbean. It has a population of about five million people and an area of 18,704 square miles. The unemployment rate in the country is estimated at between 20-40 percent, generally higher in the rural areas where 54 percent of the population lives. The country does not have any substantial domestic energy resources. Imported oil is by far the most important fuel, contributing 96.7 percent of the total commercial energy consumption and 90 percent of the total energy used for electricity generation. Recent increases in oil prices and generally depressed (although fluctuating) sugar prices have caused negative balances of trade.

It is with a view to decreasing the dependence on oil (with its attendant negative pressure on balance of trade), providing rural employment opportunities, and possible utilization of large expanses of marginal lands that the USAID Mission in the Dominican Republic and the National Energy Policy Commission requested a preliminary assessment.

This paper contains our major findings on the extent of the availability of marginal lands for biomass fuels, a suggested conceptual design for biomass farm and electric-generation facility, and an economic comparison of various biomass-filled and oil-fired electric facilities in the Dominican Republic.

Our primary findings are:

- (1) The Dominican Republic has about 8.4 million tareas* (1.3 million acres) of arid and semi-arid lands available for biomass farming. This land translates into a total potential of 200 MWe to 1400 MWe of installed electrical capacity, based on the biomass yield estimate used for these unirrigated dry forests

If lands that are presently used or potentially earmarked for agriculture or utilization of forest lands in the mountain areas are considered, the estimate of potential could be much higher.

(2) Biomass farming in the dry forest areas should be based on minimizing costs of production (rather than maximizing yields by intensive agriculture) using local farming methods with high labor input (rather than large-scale mechanization), and with minimum use of imported petro-based fertilizers in order to achieve the twin objectives of providing rural employment and reducing trade deficits.

(3) We estimate that the cost of generating electricity from wood-fired plants ranges from 5.68 centavos/kWh for a 50 MW facility to 10.06 and 14.06 centavos/KWh for a 5 and 2 MW facility respectively. The comparable costs of electricity from oil-fired plants is 12.4 centavos/KWh for a 50 MW facility. Thus, wood-fired facilities appear attractive from an economic standpoint even if smaller facility sizes with lower plant efficiencies are considered.

(4) The major challenge in implementing a biomass farming facility lies in marshalling and motivating a large force of workers to plant, tend, and harvest the biomass. A 50 MW facility needs 1,257,000 areas of dry forest land and during the establishment phase (first five years), there will be a seasonal demand (50 days) for approximately 20,000 workers. About 1,000 workers will be employed (mostly for 110 days/year), each year for the rest of the production period. Smaller plant sizes need proportionately fewer workers.

(5) Varieties of Leucanea, Acacia, and Prosopis appear prime candidates for biomass farming in the dry forest area because of their potential for rapid growth under arid conditions.

(6). Biomass farming should be considered in the Dominican Republic for other objectives such as producing wood for other uses (including charcoal).

Other specific recommendations are:

(1) A program to test methods of production and species at a site near Mao should be initiated. This site is typical of the dry forest area, is under one ownership, has a nearby source for labor, has good highway access, and most of all, will have the technical guidance of an enthusiastic staff of Institute Superior Agricultura) (ISA). In the initial stages, the Mao

site could be used for charcoal production and can augment a portable charcoal kiln program. This provides for a minimum investment option in the near term, while small-scale conversion technologies (not the subject of our inquiry) are examined exhaustively. It is also necessary to gather more accurate data on biomass farming in an arid region both on productivity and costs of establishing a farm. A key element of the cost of biomass fuel in this report is the productivity estimate which is not verified.

(2) A separate study of the relative economics and conversion technology options should be initiated for determining the potential of small (under 1 MW) biomass-fueled electrical generation facilities for remote applications. We understand that a 200 kW facility is being planned in Panama, and a 1.5-3 MW facility is being planned in the Philippines. The Government of Fiji is examining use of small wood-fired boilers and steam turbines (greater than 200kW) and village-scale producer gas units (10-40 kW) to fuel modified petrol or diesel generators.

(3) This study considered lands that were not suitable for agriculture or timber production. We believe that the issue of using highly productive lands for biomass fuel production should not be a closed one for the Dominican Republic although political and economic realities are valid concerns. It would be useful to conduct a study of economic competitiveness of various options available for timber production and agricultural lands in the framework of various world market scenarios for commodities.

(4) The scope of this study did not include market analysis. It is recommended that price/demand (location, projections, etc.) for electricity, wood, and charcoal be undertaken before capital investments are made.

(5) Because of the apparent demand for both charcoal and electricity in the Dominican Republic, a feasibility study of producing these jointly by retrofitting a pyrolysis unit to an existing oil-fired boiler should be undertaken. The Nichols-Hereshoff furnace is essentially well established technology for this purpose.

S U N F U E L S

Solar Potential Energy Conversion

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The major obstacle preventing the full utilization of solar energy is the kind of energy that it is being converted into. Wind, solar thermal and photovoltaic systems all convert solar energy into kinetic energy. Kinetic energy, or energy of movement, is very difficult to store and cannot be accumulated over long periods of time so unused or excess energy is wasted. The solution to this problem, in the long run, is not to find more elaborate storage systems but to convert the solar energy into a form which is inherently more storable, namely potential energy. Chemical energy, which is energy stored between the molecular bonds of a substance, is an excellent example of potential energy. If more processes could be developed to produce fuels, or other chemical reactions, from solar energy the benefits would be enormous. First, the problem of inadequate storage would be solved. This in turn would eliminate the need for back-up systems because excess energy accumulated during the long summer days could be "stored up" for use during the shorter winter days. Second, the right fuels could also be used for transportation which would decrease our dependency on gasoline.

Sunfuels are fuels and energy-rich chemicals that are directly or indirectly produced using solar resources. Most methods for producing synthetic fuels that are in existence today require thermal energy that could be supplied by solar systems. There also exists a variety of photo decomposition and photochemical conversion processes that utilize direct light energy to produce fuels or chemicals. Development of sunfuels, such as hydrogen, methane, liquified and gasified coal, hydrocarbons, oxygen, fertilizers, lime, and many others, will significantly add to the impact solar technologies have already made to help solve the energy crisis. Sunfuel production should be emphasized more in our nation's R&D programs, and within the solar community, to encourage more extensive research in this area.

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A discussion of the overall need for solar potential energy conversion systems, or sunfuels, will be given in more detail along with a description of the achievements that have been accomplished in this area to date. An assessment will then be made to determine in which areas R&D should be emphasized to achieve more progress.

ENERGY ASPECTS OF NEUTRAL SOLVENTS BIOSYNTHESIS AND USE

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ABSTRACT

It appears that the biosynthesis and use of neutral solvents, including n-butanol, isopropanol, and acetone, from biomass may provide significant advantages over ethanol biosynthesis and use. Comparable amounts of product are produced by both fermentations from the same feeds; however, neutral-solvents separations require a fraction of the distillation energy of corresponding ethanol concentrations due to higher volatilities of individual components and to a miscibility gap in the n-butanol - water system. The complex interactions of the components in this system have necessitated the development of a computer model reflecting both the miscibility gap and interactions between pairs of components in the system. The model was validated by bench tests. Economic and energy considerations were evaluated based on the model.

A potential use for neutral solvents would be addition to fuels, including diesel fuel or gasoline. Based on previous work in the stabilization of crude oil - water - surfactant - alcohol systems, it appeared that it would be possible to stabilize diesel oil - water emulsions, with a lowered use of surface active agents relative to previous studies. Tests in this area indicate that such emulsions can be constructed, and that they are stable across a wide temperature range. Previous literature has indicated that fuels containing a stabilized diesel - water emulsion provide for lowered vehicular NOX emissions.

AN EXPERIMENTAL ELECTRICAL GENERATING UNIT USING
SUGARCANE BAGASSE AS FUEL

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EXTENDED ABSTRACT

The cost of generating electricity in the island of Puerto Rico has risen to unprecedented levels during the last ten years. The problem stems from the fact that 99% of the generating units use imported oil derivatives as fuel.

The Puerto Rico Electric Power Authority, the public corporation in charge of the generation, transmission and distribution of electricity in Puerto Rico and the adjacent islands-municipalities of Culebra and Vieques, is analyzing other energy sources which could be viable for our system in the very near future. One of these alternate sources is the bagasse of the sugarcane.

The main purpose of this study is to present the alternatives available in the island in order to build an experimental power plant that will use sugarcane bagasse as fuel.

Sugarcane bagasse has been used as fuel for the production of electricity and steam for many years by sugar mills around the world. Hawaii, for example, produces almost 10% of its electricity from sugarcane bagasse. In Puerto Rico although sugar mills produce steam and electricity from bagasse this has decreased in recent years because of several factors. One of these factors is the bagasse "management".

Sugarcane in Puerto Rico has always been grown to produce sugar (sucrose) as its final product. The fact that the bagasse was used after the juice was extracted as boiler fuel was merely a by-product and not much thought was given to this aspect of the operation.

Eventhough not much thought was given to the fiber content of the sugarcane this has been consistent throughout the years while the sucrose content has been the one that has declined. Thus, electricity production by means of bagasse in sugar mills has declined eventhough the fiber content of the sugarcane has not changed. It is evident that if the main purpose of the sugarcane is that it is going to be used as a fuel source rather than as a sugar source then it has to be managed so as to increase its fiber content and decrease its moisture.

In view of this, it was necessary to subdivide sugarcane bagasse into conventional sugarcane bagasse (the one presently grown in Puerto Rico) and "energy managed" sugarcane when comparing it economically with other fuels such as coal and oil. Of these four fuels compared the one with the lowest cents per kilowatt hour was the energy managed sugarcane bagasse at 1.81¢/KWH.

Another aspect analyzed in the study is the amount of land which will be needed to grow the sugarcane to be used as fuel for an experimental plant (we assumed it would be a 20 MW unit). Again the analysis was done for both conventional sugarcane and "energy managed" sugarcane. As it was expected less land is needed for growing "energy managed" sugarcane (2180 acres) than conventional sugarcane (5783 acres).

Based on these numbers plus other factors such as location, equipment availability, transportation and climate we analyze the alternatives available at this moment in order to build an experimental unit using bagasse as fuel. Equipment-wise the alternatives available were a former experimental nuclear plant at the western part of the island with a turbogenerator of 17 MW capacity and three units of 20 MW capacity each presently located at the San Juan Steam Plant Complex. Location wise the alternatives where: the site were the former experimental nuclear plant is located, a sugar mill in the southwestern part of the island and two sugar mills is the south of the island.

As for the major costs involved in these alternatives they were: a new boiler for either the turbogenerator of the former experimental nuclear plant or anyone of the three units at the San Juan Complex at a cost of approximately \$2,500,000, and the cost of transporting and putting into operation the generating equipment (assembly and disassembly included) at a cost of \$1,800,000.

A brief summary is included whereby we analyze the environmental impact an experimental biomass fired unit would have.

Although we do not arrive at any conclusion as to which of the alternatives (equipment or location wise) the corporation should adopt at this moment we do recommend that a committee be set up immediately by all of the agencies that could be involved in this project (Center for Energy and Environmental Research of the University of Puerto Rico, the Sugar Corporation, the Governors Office, and ourselves, for example) to analyze the alternative presented here.

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SESSION 5C

BIOCONVERSION III

HYDROTHERMOLYSIS OF BIOMASS - PRODUCTION OF RAW
MATERIAL FOR ALCOHOL FERMENTATION AND OTHER MOTOR FUELS

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EXTENDED ABSTRACT

Introduction

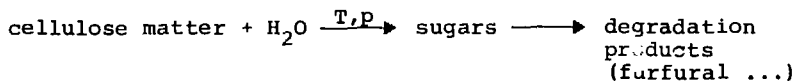
The annual world production of plant biomass is about $1,7 \times 10^{14}$ kg dry weight, which corresponds to an energy potential of $3,2 \times 10^{21}$ Joule/year /1/.

For foodstuffs and feed production as well as for energy and fibre production, only approximately 1 % respectively of the above amount is used. The remaining 98 % are unused and therefore economical methods to utilize these materials for energy purposes will be of great importance.

In the last few years we have developed a purely thermal process for the degradation of plant matter including cellulose waste /2,3/. This "Hydrothermolysis-process" represents a new method to obtain low molecular substrates to produce alcohol and other motor fuels.

The hydrothermolysis-process

The hydrolysis of plant matter is carried out with pure water at high temperatures and pressures above the relevant equilibrium pressure of water:



The sugars formed are not stable under the reaction conditions and are transformed to furfural compounds. Therefore, the residence time of the hydrolysis products in the reaction vessel must not exceed a critical value if high sugar yields are aimed at.

The hydrothermolysis apparatus

The scheme of the apparatus is shown in Fig.1. A piston pump (1) presses water from a container (2), by-passing a lift check valve (3) and a safety valve (4), through the heating system (5) to the top of the reaction vessel. The water leaves the apparatus through the heat exchanger (6) and the valve (7). If the relevant reaction temperature is reached, the valve (7) is closed and the water

flows through the reaction vessel (8), the heat exchanger (9) and the valve (10) into a fraction collector. The stainless steel apparatus was constructed to withstand water pressures up to 500 bar. The reaction vessel has a volume of 500 cm³ and is surrounded by a heating jacket. About 100 g of biomass can be introduced for hydrothermal treatment.

Results

1. Hydrolysis of pure cellulose

Filter paper was filled into the reaction vessel and water passed through at temperatures of between 260 and 272°C at a flow rate of about 350 cm³/min. An extraction profile of filter paper is depicted in Fig.2. The experiment with the highest yield of monomer sugars shows a glucose content of 68 % /4/.

2. Waste paper

The degradation was also carried out with waste paper (newspaper). The elution profile differs from that of filter paper, due to the short cellulose fibre, the lignin components and the diverse additives in newspaper. The maximum content of soluble substances in the eluate is about 10 mg/cm³, 24 % of which are glucose. The first degradations of newspaper, however, are characterized in the experiments to date by high residue values.

3. Wood

The degradation of wood (poplars) can be selectively carried out, so that first the hemicellulose and then the cellulose is converted. This can be achieved by conducting the hydrothermolysis process at two different temperatures (e.g. 180 and 265°C). These temperatures were determined in a previous series of experiments in a smaller apparatus /5/.

In the hemicellulose fraction 42 % of the original wood were found. The total yield of soluble substances after the second temperature stage amounts to 95 % of the initial wood. The glucose content does not exceed 1 mg/cm³.

The mass balance shows that also the lignin is partly brought into solution by hydrothermal treatment. These degradation products appear as lignin-carbohydrate-complexes or in a free form, the latter showing an average molecular weight of about 600 D. As can be seen from the sugar and furfural compound yields, part of the hemicellulose and cellulose is converted to water soluble, oligomeric saccharides. By a further hydrothermal treatment these products can be hydrolyzed to monomeric sugars and thus increase the sugar yields.

The sugars formed by the hydrothermolysis of cellulose matter can be used for fermentation to power alcohol (C₆- and C₅-fermentation) as well as for single cell protein production.

More than 90 % of the initial wood lignin can be transformed into a soluble form by this process /6/. These products may yield a new source for aromatics and therefore serve as fuel or fuel additive.

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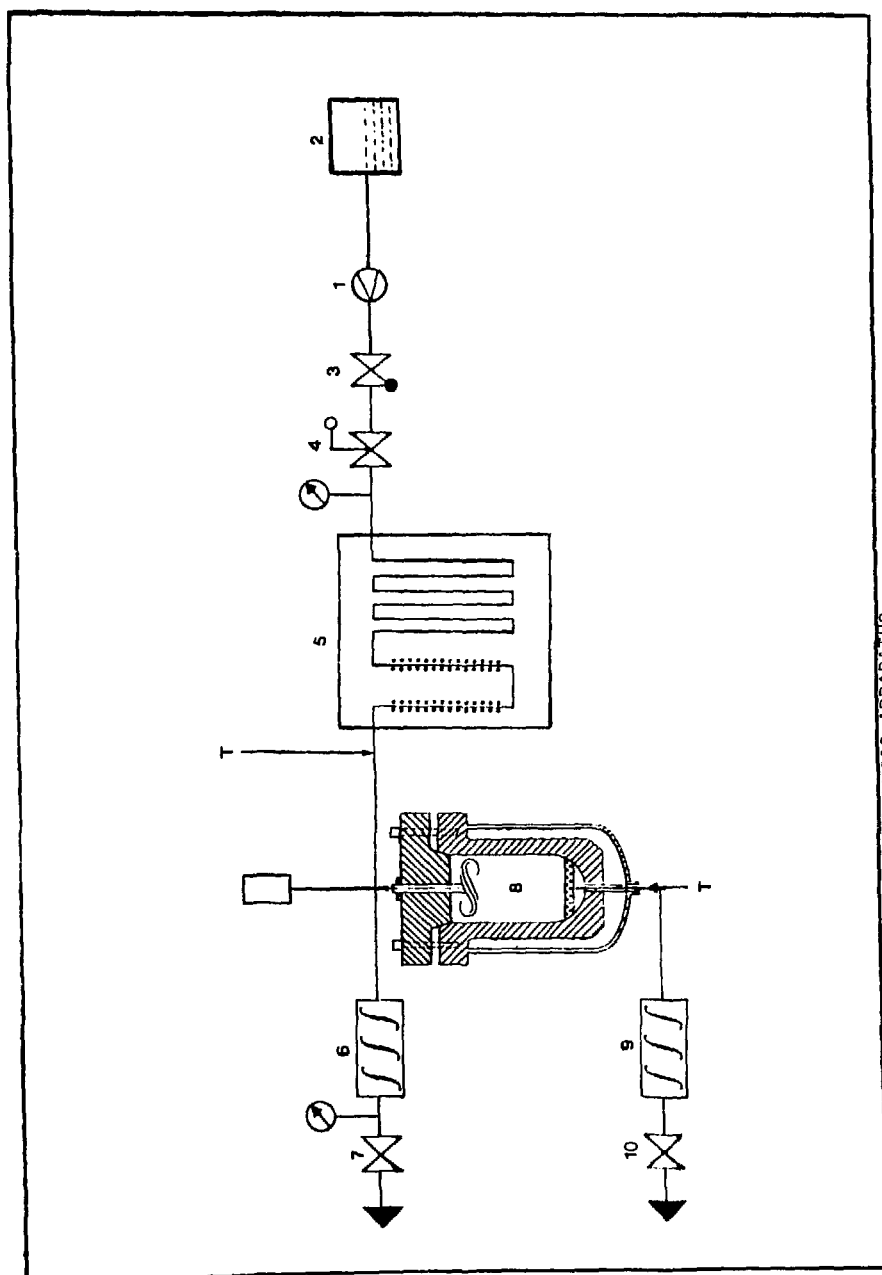


FIG. 1 THE HYDROLYSIS APPARATUS

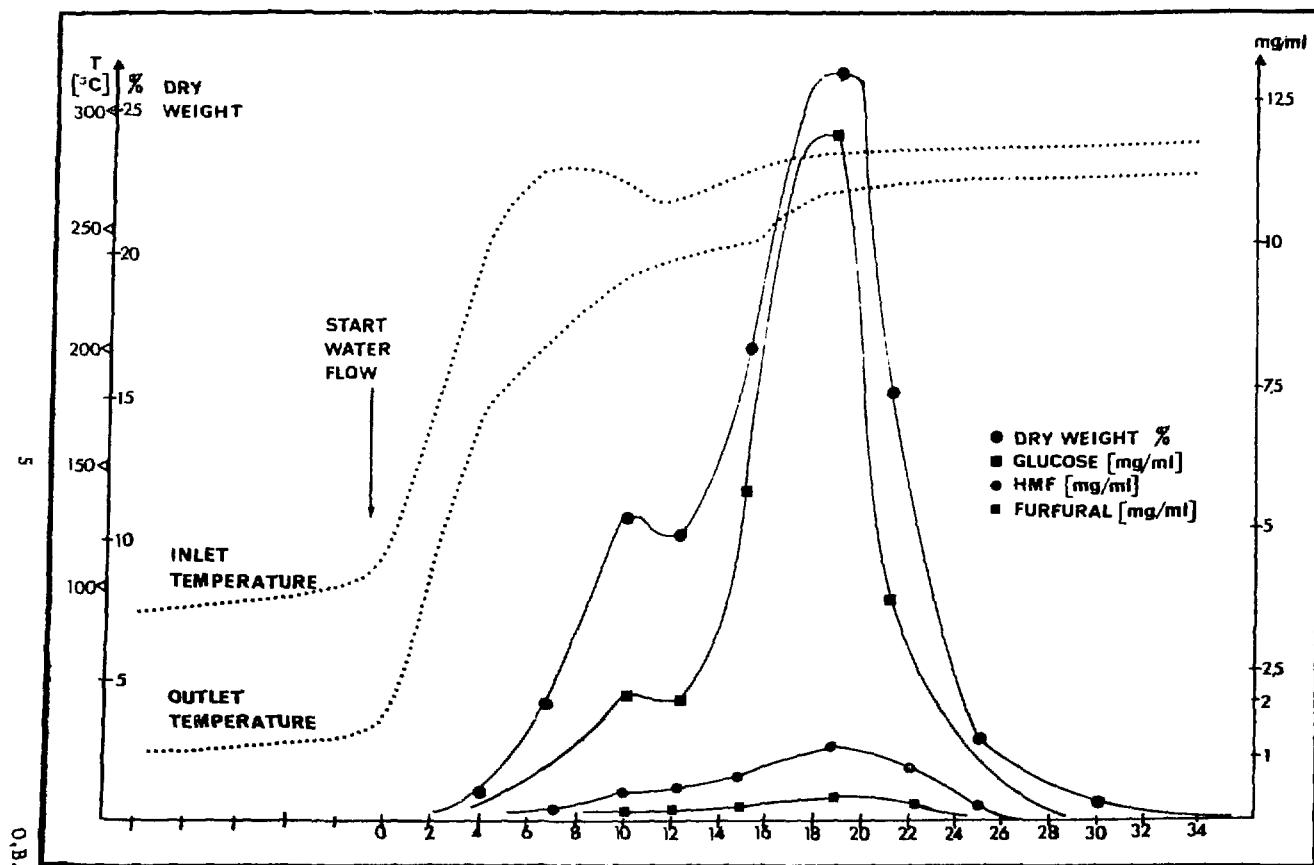


FIG.2 EXTRACTION PROFILE OF FILTER PAPER

CHEMICAL COMPARISONS OF LIQUID FUELS PRODUCED BY THERMOCHEMICAL
LIQUEFACTION OF VARIOUS BIOMASS MATERIALS

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EXTENDED ABSTRACT

INTRODUCTION

Various forms of waste biomass, in principle, can yield up to 15% of the U.S. energy requirement. This figure drops to 7% if the biomass is liquefied, but the products would contribute to solving a key problem--production of liquid fuels. This contribution is an incentive for study of the chemistry of biomass conversion.

Different forms of biomass have essentially the same constituents: cellulose, lignin, hemicellulose, humic acids, and proteins. However, the proportions of these constituents vary widely in different biomass materials. Research conducted by the Pacific Northwest Laboratory for the U.S. Department of Energy is examining the significant chemical differences in oils formed through biomass liquefaction, and is determining how such chemical differences might be industrially exploited.

EXPERIMENTAL WORK

Samples of pure cellulose, pine and spruce branches, municipal sewage sludge, peat moss, and hops residue were liquefied in the presence of a catalyst at high temperature and pressure. The biomass was mixed with enough water to form a thick slurry, sodium carbonate was added as a catalyst, and the mixture was heated to a temperature between 250°C and 400°C. The exact conditions varied, depending on sample type and on whether we were trying to influence the physical characteristics of the products.

The products that we obtained were a tar that was usually solid at room temperature, an aqueous solution of the more polar organics present, an insoluble char, and a gas. We dissolved the tars and analyzed them and the aqueous layers by glass capillary gas chromatography/mass spectrometry (GC/MS).

RESULTS AND CONCLUSIONS

The results of the GC/MS analyses of oils and aqueous solutions formed from biomass liquefaction are summarized in Table 1. The total number of compounds that we were able to identify from the products of each biomass

(a) The Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy.

TABLE 1. NUMBER OF COMPOUNDS FOUND IN BIOMASS OILS

Biomass Material	Total Number of Compounds	Hydrocarbons	Alcohols	Aldehydes and Ketones	Furans	Phenolics	Other Aromatics	Nitrogen-Containing Compounds	Sulfur-Containing Compounds	Acids and Esters
Cellulose	81	15	8	21	13	10	12	0	0	2
Tree branches	68	13	1	4	3	21	20	0	1	5
Peat moss	31	1	0	7	10	5	1	3	0	4
Sewage sludge	16	1	2	0	0	3	4	5	1	0
Hops residue	18	1	0	5	3	6	0	1	1	1

sample were further separated into nine different classifications: hydrocarbons, alcohols, aldehydes and ketones, furans, phenolics, $C_{10}H_8$ aromatics, nitrogen-containing compounds, sulfur-containing compounds, and acids and esters.

Since the product mixtures were chemically very complex, there were undoubtedly dozens of other compounds present which we could not identify. However, our information should give a good idea of the trends in chemical composition of these oils, as the compounds identified tended to be those in greatest abundance.

The significant differences in the quantities of product compounds in each classification (see Table 2) can be at least partially explained on the basis of the biomass composition. Municipal sewage sludge would be expected to be rich in proteins, so compounds containing nitrogen and sulfur ought to be fairly numerous in sludge oils. Tree branches have a higher lignin content than peat moss or hops residues, so the number of phenolic compounds should be correspondingly greater. The oils with a high percentage of aromatic and phenolic compounds have a drastically reduced percentage of furans and carbonyl compounds; one possible reason might be that the furans and ketones co-polymerize with some of the phenols. If the product oils are to be used primarily as a chemical feedstock, it should be possible to select the type of biomass that will yield the greatest amount of the desired product class.

TABLE 2. PERCENTAGES OF COMPOUNDS IN SEVERAL OF THE CLASSIFICATIONS COMPARED WITH TOTAL NUMBER OF IDENTIFIED COMPOUNDS

Biomass Type	Total Number of Compounds	Aromatic and Phenolic Compounds, %	Furans, %	Aldehydes and Ketones, %	Hydrocarbons, %
Cellulose	81	27	16	26	19
Tree branches	68	60	4	6	19
Peat moss	31	19	32	23	3
Sewage sludge	16	44	0	0	6
Hops residue	18	33	17	28	6

Although there are differences in the distribution of identified components, the biomass oils do have many similar characteristics. They are unlike petroleum-derived oils in that the quantity of hydrocarbons seems to be rather low, especially in sludge, hops, and peat oils. Phenolic compounds, though differing in quantity, are always present. In fact, the three compounds that were identified in all the biomass oils were all phenols: phenol, cresol, and ethyl phenol. A fourth, guaiacol, was found in every oil except from sludge. This means that these compounds can be produced from cellulose alone, and lignin need not be present. We suggest that the cellulose would break down under liquefaction conditions to form small ketones and aldehydes; these might condense, cyclize, dehydrate, and dehydrogenate to produce phenols.

Since phenols seem to be present to some degree in biomass oils regardless of the source, some of the problems associated with using the oils for fuel probably could not be avoided by selection of biomass type. Product corrosiveness is probably partially due to the acidity of the phenols, and high viscosity could be caused by polymerization of phenols with furans or other resident compounds. We found in our earlier work that the reaction conditions can significantly affect the potential fuel value of biomass oils, but that different types of oils produced under the same conditions all seem to have the same general viscosity.

The individual characteristics of each biomass material can be a factor in determining what biomass material to use in the liquefaction process. If the biomass oil product is to be used as a chemical feedstock, the biomass chemical makeup is important. The proportion of compounds in the biomass material determine the quantities of the resulting compounds in the oil product. If the biomass oil product is to be used as a fuel, the biomass chemical makeup is not as important as the reaction conditions. It appears that altering the reaction conditions is a more effective way to obtain desirable product characteristics when the biomass oil product is to be used as a fuel.

THERMAL DEGRADATION OF CELLULOSE IN ALKALI

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EXTENDED ABSTRACT

INTRODUCTION

Aqueous, alkaline, thermal liquefaction of cellulosic materials, available as biomass, can help reduce our dependence on natural crude oil. Liquefaction could supply liquid fuels, synthetic asphalt, and chemical feedstocks. Further study, including investigation of chemical mechanisms, is needed to improve conversion process and product use efficiency. At the Pacific Northwest Laboratory, we are focusing on liquefaction mechanisms in our ongoing work sponsored by the U.S. Department of Energy, Office of Basic Energy Sciences. I will discuss our study of chemical mechanisms and the possibility of using liquefaction products as an energy source.

OUR STUDY OF CHEMICAL MECHANISMS

To simplify the general problem of biomass liquefaction, we chose to study conversion of cellulose, the most abundant component of biomass. We reacted a 20% slurry of pure cellulose (Solka-Floc[®]) in water with at least 0.3N sodium carbonate at 270° to 400°C in high-pressure autoclaves. This process converted up to 34% by weight of the cellulose into acetone soluble oil. The other products were char, gas, and water-soluble compounds. By analyzing 17 oil samples and one aqueous sample we identified 78 compounds as cellulose conversion products. The products included polyols, furans, ketones, and aromatic compounds. Hydrogenolytic cleavage may lead to the polyols. The furans and cyclic ketones may result from cyclization of diketone intermediates formed by aldol condensation of simple initial cellulose degradation products such as acetone and acrolein (propenal). Experiments reacting these simple compounds under the same conditions yielded six of the same furan and ketone products as identified from cellulose conversion, supporting five of our predicted mechanisms. Currently, we are studying the formation mechanisms of the hydrocarbon and aromatic compounds identified in the conversion products.

(a) The Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy.

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POSSIBILITY FOR PRODUCT USE AS AN ENERGY SOURCE

The liquid products of thermal degradation of cellulose in alkali contain more than half the energy of the starting material even though they only contain a third of the mass. We found that as much as 68% of the energy in the original cellulose was available in the product oil. For 25 conversion experiments the average heat of combustion was 7800 cal/g (14,000 Btu/lb).

Although in our basic research we have used pure cellulose, we have also liquefied peat moss, hops residue, and sewage sludge. In fact, any wet, finely divided biomass can be liquefied. However, before the liquid products could reasonably be used as fuels, further study is necessary to reduce problems such as high viscosity and the presence of corrosive compounds in the products. Our study of mechanisms will aid in process development by identifying appropriate feedstock, reaction conditions, and final products.

SUMMARY

Biomass is a renewable energy resource that can produce liquid fuel by aqueous, alkaline, thermal degradation. Better understanding of the conversion technology's basic chemistry will help us use this resource more efficiently.

USE OF CATALYSTS IN BIOMASS GASIFICATION

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EXTENDED ABSTRACT

INTRODUCTION

Natural gas and petroleum-derived hydrocarbons are widely used as a source of organic raw materials in the synthesis of special products such as ammonia, methanol, and other valuable chemicals. Projected shortages of natural gas and petroleum feedstocks require that government and industry search for other sources of organic materials to provide substitute feedstocks for chemical synthesis. The Department of Energy (DOE) is currently funding a number of investigations to determine if coal or other carbonaceous materials such as biomass can serve as this substitute.

At the Pacific Northwest Laboratory (PNL) operated for DOE by Battelle Memorial Institute, studies are in progress on steam gasification of biomass (wood) in the presence of catalysts. Yields of high-value, gaseous products in a single reaction stage are enhanced by the proper choice of reactants, operating conditions, and catalyst combinations. Gaseous products successfully produced by the various steam gasification systems employed to date include synthesis gases for hydrocarbon, methanol, and ammonia generation and a methane rich gas.

The practiced state-of-the-art procedure for conversion of a carbonaceous material to a synthesis gas involves several steps. These include: 1) gasification by partial combustion with pure oxygen and steam to form a mixture of gases (CO , H_2 , CO_2 , CH_4 , H_2S), 2) reforming of hydrocarbons, 3) shift conversion to yield a 2:1 H_2 : CO ratio in the gas mixture, 4) acid gas removal, 5) moisture removal, and 6) further gas cleanup to remove traces of sulfur compounds that would otherwise poison catalysts. Partial combustion of the carbonaceous material with pure oxygen to provide heat for the endothermic steam decomposition reaction is currently practiced for gasification to produce a methanol or hydrocarbon synthesis gas mixture. An expensive, energy consuming oxygen plant is, therefore, required for these gasification processes to avoid dilution of the product gases with nitrogen. Conversion of wood to hydrocarbon synthesis gas is simplified somewhat because of the negligible sulfur content of wood, but still involves the steps of gasification, shift conversion, reforming, CO_2 removal, and moisture removal.

The objectives of the studies at PNL are to determine the technical feasibility of catalytic processes for gasification of wood to specific products and to evaluate the economic feasibility of the technically

feasible processes. Processes for generation of a methanol, or hydrocarbon synthesis gas and a methane rich gas appear to be technically feasible and are described in this paper. Economic feasibility studies on these processes are in progress.

CATALYTIC GASIFICATION PROCESSES

Studies at PNL have succeeded in developing processes that produce the required gas products in a single reactor system through the use of catalysts. No oxygen plant is required, and only moderate gas cleanup is needed. These studies are being performed in the laboratory and in a 50 lb/hr process development unit (PDU).

Wood is gasified by contact with high temperature gaseous reactants in the presence of catalysts. Pressures up to 10 atm are desirable; however, most work to date has been at atmospheric pressure.

A methane-rich gas is obtained with steam as the reactant at temperatures from 550°C to 650°C in the presence of a nickel catalyst system. Increasing the temperature to the 750°C to 850°C range results in a hydrogen and carbon monoxide gas mixture suitable for synthesis of methanol or hydrocarbons.

Methane Generation Laboratory studies showed that a 50% methane mixture with carbon dioxide could be generated in a single stage gasifier. The conditions required that a secondary nickel-silica/alumina catalyst bed at the exit to the gasifier be maintained at an exit temperature of 350°C. Carbon dioxide removal is all that is necessary to make pipeline quality gas. Uniform temperatures from 550°C to 650°C in the gasifier have resulted in a gas mixture with about 25% methane, 30% hydrogen, 15% carbon monoxide and 30% carbon dioxide. This gas mixture would require further methanation as well as carbon dioxide removal to be pipeline quality. The projected methane yields range from 310 to 340 nm³/MT dry wood (10,000 ft³/t).

Proposed processing schemes based on laboratory and PDU results are presented. Equilibrium calculations indicate that the reaction system is only slightly endothermic at 600°C and 10 atm pressure. Methods for supplying the heat requirements indirectly are discussed.

Synthesis Gas Generation In this paper, synthesis gas is defined as a mixture of hydrogen and carbon monoxide in the proper proportion for methanol or hydrocarbon production. Generation of synthesis gas is affected by contact with steam and secondary catalysts at temperatures above 750°C. Catalyst properties require that the endothermic heat be supplied to the system indirectly. Potential designs for adding the endothermic heat are discussed.

Laboratory studies and preliminary feasibility analysis have indicated that a methanol yield of 0.6 kg/kg dry wood can be attained at an overall energy efficiency of 65%. PDU studies are in progress to verify

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these results and to evaluate catalyst lifetime. Operating problems with the PDU have primarily centered on maintaining a uniform fluid catalyst bed at the required temperature.

Process and gasifier design considerations for synthesis gas generation are presented. Operating results from the fluid bed PDU are the basis for design considerations.

DESIGN AND OPERATION OF SMALL BIOGAS PLANT

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EXTENDED ABSTRACT

This paper represents some of the work activities of the engineering group in connection with an integrated national R & D demonstration project for the implementation of biogas technology in rural areas of Egypt. These activities are mainly directed toward design, construction and operation of biogas plants, together with the development of gas-use devices.

The paper concentrates on the experience gained from the adaptation of the Chinese biogas technology. Two types of Chinese digester have been constructed. The first is a 10 M³ rectangular digester of the water pressure type, and the second is a 6 M³ circular and shallow digester with domed roof and dished bottom. Both digesters are of the fixed roof gas holder, and were constructed from locally available conventional building materials. The construction of the first digester was undertaken through a contractor which resulted in very high initial cost and suffered from some leakage problems. The second digester, although being much more complex and critical in its construction have been constructed by trained skilled labours, and could be operated very successfully. This resulted in high reduction in construction cost.

The design criteria, structural theory, construction technique, building materials and cost estimation of the circular digester are described in this paper.

A third prototype unit of an effective size of 7 M³ has been recently constructed. It combines the features of both plug flow and the Indian movable cap types. Provisions for solar heating of feed water, composting of the digester effluent on the top of the plug flow part and attachment to both latrine and an animal shed were incorporated in the unit.

Some operation and performance data of the circular digester are presented in this paper. This covers the effects of the variation in the ambient temperature on the internal digester temperature, the effects of digester temperature and pressure on the gas production rate and gas composition.

Development and design of rural biogas burners are being described. Design calculations of three size-units are tabulated.

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Rough estimate of the biogas that could be produced by utilization of crop residues already used as energy sources as well as animal and human wastes available, indicated that the biogas could provide the major portion of the residential rural energy requirements.

- 2 -

AMA

THE ROLE OF BIOGAS TECHNOLOGY IN ENERGY PLANNING FOR INDIA
AND COST BENEFIT ANALYSIS ON SOME INDIAN BIOGAS PLANTS

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EXTENDED ABSTRACT

INTRODUCTION

The key role of bio energy from the utilization of available biomass in the form of agricultural residue, forest residue and animal waste to supplement the energy requirements of India while providing clean environment and the potential of bio energy to off load the demand on conventional fuels are discussed.

Potential of Biogas Production in India The necessity of rapid expansion of biogas digesters is a big way as a major current innovation in biomass utilization to meet the energy requirements for socio-economic development of rural areas in India is projected in Tables 1 and 2. These tables have been prepared keeping in view the average of reference and optimal level forecast of non commercial energy demand in India (1) for the years 1982-83 and 1987-88. The method of calculations and energy conversion factors used are from references 2,3 and 4. The present stage of this art in India is briefly reviewed. Different sizes of biogas plants designed in India as envisaged in Tables 1 and 2 are analysed with respect to their feed requirements, gas generation capacity, cost of construction and finally their suitability for application in rural as well as urban areas. The viability of small scale family type of units to produce biogas with cow dung, vegetable offal and dried leaves for cooking and lighting in the house hold is discussed. The performance of a small family size digester designed and operated by the authors using the agricultural wastes such as sugar cane leaves, banana leaves and Ipomea cornua leaves along with cow dung to find out their suitability for using in a community plant to generate power for agricultural operations like pumping water to farm lands is presented. The cost benefit analysis for existing KVIC (Khadi and Village Industries Commission) design of biogas plants of different sizes is given in Table 3. For such type of plant rate of return on investment is worked out. Optimum sizes of gas holder and digester as given in reference 5 for the sizes of plants namely family size, community plant and industrial type are shown in Table 3.

TABLE 1 BIOGAS DIGESTERS THAT COULD BE BUILT OUT OF AVAILABLE AGRICULTURAL WASTES IN INDIA

Available source	42 Million Tons of Agricultural Waste per year (35.22 MTCE)		
Energy Potential	35.78 x 10 ¹² K Cal		
Realistic Approach with 15 percent overall conversion Efficiency	5.36 x 10 ¹² K Cal Available		
Biogas that can be produced	1096 x 10 ⁶ M ³ / Year		
Saving on conventional fuels	4.6 Million tons of coal replacement or 0.55 x 10 ⁶ Tons of kerosene		
Type of Digester	Capacity M ³ / day	Requirement of Ag. Waste in Percent of source	Number of Digesters in thousands
Family size	2.83(100ft ³)	60	636
Medium size	9 (317ft ³)	25	83
Community plant	56.6(2000ft ³)	8	4.2
Industrial type	85 (3000ft ³)	7	2.4

TABLE 2 GOBAR GAS POTENTIAL FOR ORGANIZING VARIOUS TYPES OF DIGESTERS IN RURAL AND URBAN AREAS OF INDIA

Available source	1000 Million Tons of cattle dung per year		
Gobar gas that could be produced per year	37000 x 10 ⁶ M ³		
Saving on conventional fuels	155.4 Million tons of coal replacement or 18.7 x 10 ⁶ tons of kerosene		
Type of Digester	Capacity M ³ / day	Requirement of dung in percent of source	Number of digesters (in Millions)
Family size	2.83(100ft ³)	56	20
Small size	6 (212ft ³)	30	5
Medium size	9 (317ft ³)	8	0.9
Community plant	56.6(2000ft ³)	3	0.053729 (53729thousand)
Industrial type	85 (3000ft ³)	3	0.035647 (35647thousand)

TABLE 3 COST BENEFIT ANALYSIS ON KVIC DESIGN DIGESTERS
BASIS: 1.6M³(35.31ft³) Biogas replaces 1 liter
Kerosene of cost Rs.1.60

Capa- city of plant ft ³ /day	Diameter		Height		Total cost Rs	Cost per ft ³ of gas Rs.	Re- turn on Inves- tment per- cent
	Gas holder D _k ft.	Digester D _k ft.	Gas holder h _k ft	Digest- er h _k ft			
100 (2.23 M ³)	5.23	5.23	2.69	13.72	3055	30.5	11.6
200 (5.66M ³)	6.70	7.20	3.40	17.36	4639	23.2	20.4
300 (8.5M ³)	7.69	8.19	3.87	19.77	5994	19.9	26.3
2000 (56.6M ³)	14.48	14.98	7.30	37.18	19107	9.6	31.3
3000 (85.0M ³)	16.58	17.08	8.34	42.54	25285	8.4	36.2

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THE BIOMASS GASIFICATION PROJECT AT THE UNIVERSITY OF FLORIDA

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The Institute of Food and Agricultural Sciences (IFAS) at the University of Florida began a biomass gasification project in July, 1979. The project has three parts. The first is to develop demonstration units to show the possibilities of gasification for application in the agricultural and forest industries of Florida and second, to study the gasification process, gasifier design and the gasification qualities of fuels available in Florida and third, to gain experience with gasifier units in routine working situations by finding local cooperators willing to install and use a gasifier unit with appropriate monitoring by the University of Florida staff.

The following units are complete or under construction:

I. Mobile Units

1. Truck
2. Tractor

II. Stationary Units

1. 5 Kw generator - spark ignition engine - portable.
2. 20 Hp band resaw - spark ignition engine - to work in a local sawmill.
3. 50 Hp dual fueled diesel pumping unit.
4. Crop Dryer - self contained - producing drying heat and power for fans.

The following studies are underway or planned:

1. Measurement of temperature and gas composition at various

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positions inside a gasifier as a function of fuel throughput and gasifier design factors.

2. The fuel properties of the gas produced from different biomass feedstocks.
3. Mass and heat balance and efficiency of different gasifier designs.
4. The use of producer gas as feedstock for biological conversion to methane.

CONVERSION OF SOLAR ENERGY TO
LIQUID FUEL VIA ALGAE

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EXTENDED ABSTRACT

INTRODUCTION

In the search for alternatives to petroleum fuel, much attention is currently being focused upon agricultural sources. One constraint is the low yield of biomass exhibited by land-based crops. Algae have some inherent advantages over such crops. Their yield is higher, and because they can be harvested by pumping, they should be more economical to harvest, once the technology to separate them easily from water is developed. Accordingly, we have investigated both the theoretical and economic aspects of growing algae and processing them to ethyl alcohol.

THEORETICAL MAXIMUM YIELD

According to scientists' present understanding of photosynthesis, 8 to 12 photons of light (400-700 nm) are required to reduce a molecule of CO₂ to carbohydrate, as depicted by equation 1:



If the quantum requirement is assumed to be 10, and a value of 167 kJ (40 kcal) per einstein is assumed for light of 700 nm wavelength, then a minimum of 1.67 MJ (400 kcal) of energy must be used for each mole of CO₂ reduced.

Although 1.67 MJ is required by the process, only a fraction of this energy is captured and stored as carbohydrate. This can be seen by considering that one mole of glucose (C₆H₁₂O₆) contains 2.86 MJ (684 kcal) of chemical potential energy; therefore, the energy content of a mole of CH₂O is only about 2.86/6 = 0.476 MJ (114 kcal) or 15.9 MJ/kg (3.81 kcal/g). Thus the maximum efficiency of energy conversion by photosynthesis is 0.476/1.67, or 28.5 percent. This efficiency could never be obtained in natural sunlight, because only 45 percent of solar radiation is of wavelength 400-700 nm, which can be absorbed by photosynthetic pigments (1).

An additional 6 percent of the radiation is lost to heat within the trapping center pigments of the two photosystems (2). This reduces the fraction of sunlight that is used from 45 percent to 42.3 percent. Because only 42.3 percent of the incoming solar radiation can possibly be converted to chemical energy, and of this, only 28.5 percent is stored as carbohydrate, the overall maximum efficiency is

$$0.423 \times 0.285 = 0.121, \text{ or } 12.1 \text{ percent.} \quad (2)$$

For southern New Mexico where the annual solar energy input is 8.195 GJ/m^2 (7.914 Tcal/acre), this efficiency could provide 9.92 MJ/m^2 (950 Gcal/acre , of chemical energy yearly. If the biomass were all carbohydrate with a caloric content of 15.9 MJ/kg (3.81 kcal/g), the yield of biomass (dry basis) could be $62.4 \text{ kg/m}^2\text{yr}$ (275 T/A-yr):

$$(0.121) \left(\frac{8.195 \text{ GJ}}{\text{m}^2 \text{ yr}} \right) \left(\frac{1 \text{ kg CH}_2\text{O}}{15.9 \text{ MJ}} \right) = \frac{62.4 \text{ kg carbohydrate}}{\text{m}^2 \text{ yr}} \quad (3)$$

Of course, not all the cell mass is carbohydrate; much is protein, so the energy content is greater than 15.9 MJ/kg . The actual yield is further reduced because of reflection of sunlight at the air-water interface and transmission losses in the algae culture medium. Finally, there will be losses due to respiration during darkness of about 10 percent (3). Losses due to photorespiration during daylight might be inhibited by providing an artificial environment with a high CO_2 concentration. Under such conditions, we estimate that algae can be grown at the rate of $36 \text{ kg/m}^2 \text{ yr}$ (160 T/acre yr).

ALGAE FARM AND ALCOHOL PLANT

A conceptual design for a commercial process is presented in figure 1. Algae would be grown and harvested continuously, then the cells would be degraded by enzymatic hydrolysis and fermented to produce ethanol. The ethanol would be concentrated to 190 proof by distillation. Protein would be recovered from the biomass residue and from the still bottoms, then sold as livestock feed. Waste liquids would be treated, then recycled to the algae farm.

The capital cost of such a farm and alcohol plant, yielding $36 \text{ kg/m}^2\text{yr}$ of algae and producing 3.0 GL of alcohol per year, would be about \$2.7 billion. If the facility were to realize a 10 percent return on investment, the alcohol would have to be sold at $\$0.33/\text{L}$ ($\$1.25/\text{gal}$). If the protein were sold as cattle feed at $\$0.44/\text{kg}$ ($\$0.20/\text{lb}$), the project would be even more attractive, and the alcohol price could be reduced to $\$0.18/\text{L}$ ($\$0.68/\text{gal}$). Other factors which would greatly affect the profitability of the venture are the capital cost of the algae culture basins and the utility costs.

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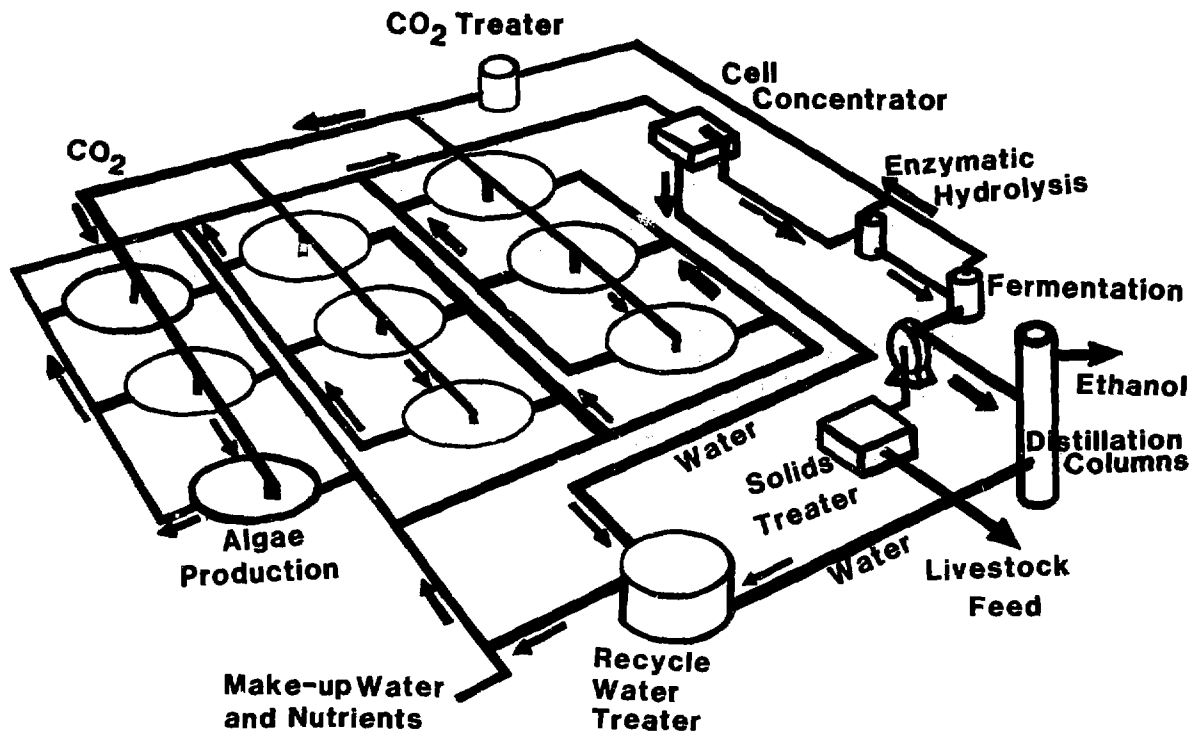


FIG 1 Algae Farm and Alcohol Plant

ECONOMICS OF PRODUCTION OF MICROALGAE IN HIGH INTENSITY MASS
CULTURE, AS A NEW SOURCE OF FUEL OILS

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INTRODUCTION

The objective of this paper is to examine algal lipids as an energy source. Biomass farming for the production of either trees, sugar cane, or aquatic plants has been suggested as a major source of fuel for the future. However after plant biomass has been produced, extensive and costly processing is required to produce usable gaseous or liquid fuels. Microalgae have also been suggested as a biomass source for the production of methane through anaerobic digestion. But under controlled growth conditions, microalgae can produce lipids at up to 80% of the algal dry weight. The lipid has a high energy content (equivalent to sunflower oil) and is easily extracted from the algae. In addition, algal productivity may be as high as 50 tons dry weight per acre-year compared to 20 tons per acre-year for trees.

Previous Work Algal cultures have been intensely studied as a potential source of protein and more recently as a potential source of energy. (1) Productivity as high as 43 g. dry wt./m²-day have been obtained in small laboratory cultures (2). However, in large outdoor cultures reported productivity is much lower ranging from 21 to 1 g dry wt./m²-day. Low productivity in outdoor culture has limited commercial development of algae as a source of fuel and chemicals. Most outdoor culture systems have been gently stirred ponds or raceway systems and have not been engineered for maximum productivity.

The use of algae as an energy source has centered on anaerobic digestion of algal biomass to produce methane (4). Although anaerobic digestion is energy efficient, capital costs are high due to long residence times and low loading rates. However, under proper growth conditions some algae produce chemicals with a high energy content. During nitrogen limited growth *Chlorella pyrenoidosa* produces 80% of its dry weight as lipid (3). The lipid is easily extracted using a methanol/acetone solvent to yield a high energy content oil and a protein by-product concentrate.

Experimental and Modeling Work *Chlorella pyrenoidosa* was grown in continuous culture in a two liter "Bioflow" fermentor (New Brunswick Scientific) using the medium of Starr (4) at a constant temperature of 25°C. The fermentor was illuminated with a tungsten light at 15,000 lux and a 0.3% CO₂-air mixture was sparged through the fermentor at 20 S.L.H. Samples were withdrawn from the fermentor daily for optical

determination of algal dry weight. Once steady state was established a 40 ml sample was withdrawn for determination of lipid content and fatty-acid distribution as set forth by Kates (5).

Modeling of algal productivity was based on a simple growth model which accounts for light saturation of growth and respiration. The specific growth rate of algae, μ , is given as:

$$\mu = \frac{\mu_m I}{K_s + I} - k_r \quad (1)$$

where μ_m = the maximum specific growth rate
 I = the light intensity
 K_s = a saturation constant and
 k_r = the respiration constant

The light intensity at any depth in the culture is taken as

$$I = I_0 \exp(-\alpha X z) \quad (2)$$

where I_0 = the incident light intensity on the surface of the culture
 X = algal dry weight
 z = culture depth and
 α = the average Beers law constant

Equation (2) is used to substitute for I in Equation (1). Integrating the resulting equation over the culture depth, d , and noting that the average growth rate in continuous culture is equal to the dilution rate, D , yields a working equation for surface area productivity, P_{sa} , of an algal culture of

$$P_{sa} = x d \left\{ \mu_m + \left(\frac{\mu_m}{\alpha x d} \right) \ln \left[\frac{I_0 + K_s}{I_0 + K_s \exp(\alpha x d)} \right] - k_r \right\} \quad (3)$$

Results Continuous cultures of *C. pyrenoidosa* yielded algal lipid contents ranging from 21% without nitrogen limitation to 78% with nitrogen limitation. Algal productivity ranged from 26.8 to 10.3 g dry wt/m²-day. High productivities were obtained at low algal lipid content. Fatty acid analysis showed the algal lipid to be similar to corn oil and having a calculated energy content of 17,100 BTU/lb.

The simple model for algal productivity predicted fermentor performance very well. Initial verification of the model was conducted using K_s , μ_m and α determined by Tamiga et al (3). Based on this model a large scale process design was developed for production of algal lipids. With optimal culture depth and cell density productivities of 32.5 tons per acre-year were predicted. The capital cost of a 110 acre culture facility was estimated at $\$2.4 \times 10^6$. Assuming a selling price of $\$0.20/\text{lb}$ ($\$1.58/\text{gal}$) for algal oils and $\$0.10/\text{lb}$ for algal protein concentrate a simple return on investment of 39% was calculated.

This economic analysis should be viewed as a preliminary estimate, but it does point out the potential for production of algal lipids as an energy source. Experimental work with pilot and demonstration scale algal culture systems is needed before a detailed economic analysis can be developed. Work is now planned at Battelle-Northwest on larger scale algal cultures (up to 40,000 l) to develop control strategies to optimize productivity, methods of species control and efficient harvesting methods.

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WOOD FUEL PROCESSING: AN ECONOMIC ANALYSIS

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The nonforest products industry is confronted with a wide variety of options when it decides to switch to wood fuel. Should wood residue be purchased as fuel, or are whole tree chips preferred? What type of boiler and burner are indicated? Is drying or pelletizing wood economically attractive? This paper quantifies the total cost to the user for each wood fuel processing route. The cost for wood fuel is added to the amortized cost of the capital equipment, plus other charges such as maintenance and operation costs. This total is the cost of heat (typically as steam) in dollars per million Btu's delivered. These costs are drawn from data compiled on wood fuel properties and cost, size reduction, handling and storage, drying, densification, gasification, liquefaction, combustion, and process routes and economics.

Each potential route is analyzed as a process diagram with blocks representing the various equipment required to produce energy. Equipment cost is estimated in cost per ton per hour of fuel throughput, boilers rated in dollars per pound of steam capacity, fuels on a cost per million Btu, as fired. Operating costs, maintenance costs, and tax and insurance costs are estimated from historical data. All of these costs are displayed in graphical form, where possible, to aid the user or designer in developing cost estimates and comparisons on competing process routes. Details of calculation techniques and methodology are also provided.

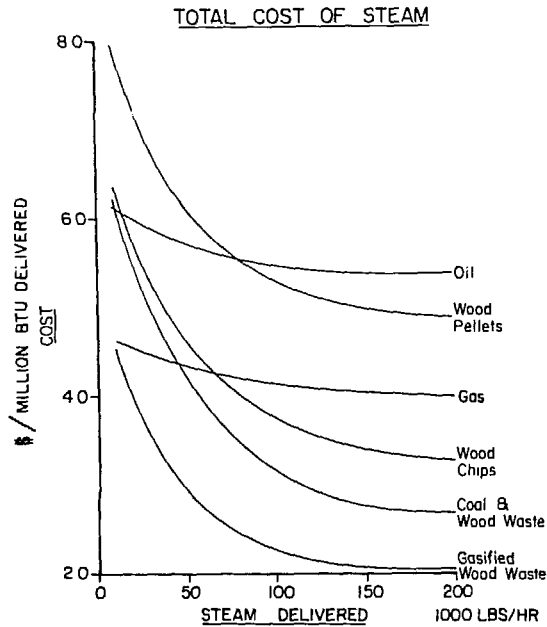
Major emphasis is placed on commercialized processes such as direct combustion of wood in boilers. State-of-the-art topics like wood densification and gasification are examined in detail for future commercialization. Processes which are still in the experimental stage are dealt with briefly to assess market areas and provide rough cost estimates. The data is presented from the wood user's point of view. Fuel prices are given on a delivered basis and total costs are compared with those for gas, oil, and coal. Fuel price data and capital cost are based on the State of Georgia, and have application throughout the Southeast.

The results of the economic analysis of wood derived liquid and gas fuels is found in Table 1. The total cost of each product is based on capital, operating, and fuel costs.

Table 1
COST TO PRODUCE WOOD DERIVED LIQUID AND GAS FUELS

<u>Fuel</u>	<u>Cost/Unit</u>	<u>Cost/Million Btu's</u>
Ethanol	\$1.31/gal	\$15.50
Methanol	\$.84/gal	\$13.00
Pyrolysis Oil	\$.60/gal	\$ 5.17
Pyrolysis Char	\$114./ton	\$ 4.32
Catalytic Oil	\$1.35/gal	\$ 9.10
Low Btu Gas	\$.39/Mcf	\$ 2.57

Figure 1 is a summary of the total cost of producing steam with wood fuels, and includes a comparison to natural gas, oil, and coal. This graph shows that wood chips and wood waste are cheaper than gas and oil, and competitive with coal for medium to large boiler capacities commonly found in industry.



LOGGING RESIDUES: AN ECONOMIC ENERGY SOURCE?

A study of the feasibility of utilizing logging residues
from Pacific Northwest coastal forests.

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EXTENDED ABSTRACT

INTRODUCTION

Vancouver Island lies along Canada's Pacific Coast about 50 kilometres west of the mainland of British Columbia. It is typical of many areas of the Pacific Northwest and Alaska in that its economy is dominated by the forest industry. Forest and mill operations presently use over 3 million barrels of oil and a million units of hog fuel annually. In addition, the forest industry consumes over half of the electrical energy produced on the island.

On Vancouver Island each year, over 3 million tonnes of logging waste are generated in the forest harvesting operations. This material, which is sufficient to produce over 400 megawatts of power, is presently unutilized due to the lack of an efficient residue harvesting and processing technology. If equipment and methods can be developed to recover and utilize logging residues at a cost competitive with fuels now in use it would be possible for the forest industry to achieve a higher degree of energy self sufficiency.

INCREASING DEMAND FOR WOOD RESIDUES

In response to increasing petroleum costs, consumption of wood residues is expected to increase rapidly in the 1980's as many existing wood processing plants convert from oil and gas to mill residues (mainly hog fuel) for their energy requirements. This is expected to put severe pressure on supplies of hog fuel and thus to focus the attention of the forest industry on the use of logging residues as a supplementary fuel stock for the generation of process steam and power.

RESEARCH AND DEVELOPMENT REQUIRED

To develop a suitable technology for collection and processing of logging residues into fuel stocks and to determine the technical and economic feasibility of utilizing logging residues for energy, Forestal International Limited was retained by the Canadian Forestry Service to develop and test a field treatment system for logging residues.

The project was funded as a part of the \$30 million, Energy from the Forest (ENFOR) program of the Canadian Forestry Service. The objective of ENFOR is to conduct research, development and demonstration projects which will lead to the replacement of up to 8 percent of Canada's total primary energy requirements now being met with fossil fuels, with forest biomass by 1985.

SITE SELECTION AND INVENTORY

Two test sites were selected to represent the range of residue quantities and piece sizes which one could expect to encounter on typical Pacific Coast logging operations.

An inventory of logging residues was carried out to determine the quantity per unit area, piece size distribution and condition of the material. On the old growth site, where the forest was overmature, the concentration of residues was heavy (185 tonnes per hectare); piece size was variable with pieces greater than 50 centimetres in diameter accounting for over 40 percent of the total; and the proportion of rotten material was high (43 percent) due to the high degree of dead and decayed wood present in the old growth forest. On the young, second growth forest site, the concentration of residues was light (55 tonnes per hectare); piece size was relatively constant with pieces greater than 50 centimetres in diameter accounting for only 3 percent of the total; and the proportion of rotten wood was low (17 percent). Land firm stumps were not included in the inventory as they were to be left in the ground for erosion control.

RESIDUES ASSEMBLED AT ROADSIDE

Residues were collected from both the old growth and second growth sites and piled at points which would be accessible to portable wood processing equipment. Small crawler tractors were used because of their ability to work between stumps and to minimize the amount of dirt and rocks picked up with the residues. These machines operate at a relatively low cost and can be used with a variety of attachments. A brush blade attachment was used to collect and pile residues over short distances. For material located at greater distances from the chipper access point, a brush grapple was used to carry the material which had been prebunched using the brush blade. This system worked well at both sites. A reinventory showed that recovery, as a percentage of the original material inventoried, ranged from 85 percent on the second growth site to 95 percent on the old growth site. Costs averaged \$7.50 per tonne collected based on an average productivity of 30 tonnes per machine-day.

MOBILE CHIPPERS TESTED

Due to the differences in characteristics of the residues on the two sites, two different mobile chippers were selected for field processing trials. To accommodate the larger pieces encountered on the old growth site a two-stage reduction system was required. A splitter mounted on a crawler loader was used to break down large logs and windfall roots prior to chipping. Smaller pieces and split chunks were fed into the hopper of a proto-type drum chipper which reduced the material into chips of 50 to 100 millimetres in length. The chips were carried by a conveyor into a van.

On the second growth site, where the average piece size was considerably smaller, a Nicholson 22-inch (55 cm) mobile drum chipper was used. The chipper infeed opening was sufficiently large to handle most of the material on the site without the use of a splitter. The chipper was fed by a horizontal belt capable of feeding material at a rate of 30 lineal metres per minute. Due to the small size of the material being handled it was not possible for the chipper's grapple loader to keep this belt full at all times. A small crawler loader was used to assist in feeding material from the piles. The chipper produced small chips (25 to 50 millimetres in length) which were blown through an outfeed duct into a van.

Under optimum conditions the two-stage, split and chip system was capable of producing 17 tonnes per day at a cost of about \$35 per tonne. The chipper operating in small second growth residues could achieve a production of 80 tonnes per day for a cost of about \$15 per tonne. Average costs incurred on the field trials were considerably higher due to the experimental nature of the project.

DELIVERED COSTS: \$30 to \$50 PER TONNE

Based on experience gained during transportation trials it is estimated that it will cost \$5 to \$10 per tonne to transport processed forest residues to conversion plants located from 25 to 75 kilometres from the loading points.

The combined collection, processing and transportation costs based on optimum operating conditions would range from \$30 to \$50 per tonne.

ENERGY POTENTIAL

Processed material from the test sties was analysed to determine its energy value. It was found that one tonne of sound, processed forest residues in an air dried condition (55% moisture content) has a potential energy value equivalent to about 225 litres of fuel oil. At the present cost of fuel oil in Vancouver (\$0.17 per litre), the potential value of a tonne of processed forest residue would be about \$38. Considering the difference in combustion efficiencies of oil (82.5%) and wood at 50% moisture content (72.75 %) the value of these residues in terms of replacement fuel would be about \$33.50 per tonne.

ENERGY PRODUCED VS. ENERGY CONSUMED

Fuel consumption for all phases of the project was monitored and the heating value of this fuel was compared with the average heating value of the processed forest residues. It was found that on a unit basis, logging residue contained about 10 times the energy value of the fuels consumed in collecting, processing and transporting it to a conversion plant.

AT WHAT POINT WILL UTILIZATION OF RESIDUES BE ECONOMIC?

An analysis was carried out to determine the net effect of increase in the value of logging residues due to increase in the price of alternative fuels and the increase in cost of residues due to increases in cost of fuels consumed in the collection, processing and transportation operations. Based on the delivered cost estimates developed on this project, the point of equal cost and value for the higher cost two-stage splitting and chipping operation would be at a point when fuel oil costs reach \$0.24 per litre (a 40 percent increase over present costs). For the lower cost (Nicholson) chipping operation in small diameter second growth residues, the delivered cost (\$30 per tonne) is already 10 percent less than its present value (\$33.50 per tonne) in terms of a replacement fuel when oil costs \$0.17 per litre. However, fuel stock costs are not the only factor to be considered.

It should be noted that the above rationale does not take into consideration the difference in capital and operating cost of wood and oil fired boilers. Because of the bulky nature and high moisture content of wood fuels, steam plants using wood fuels cost from two to four times more than oil fired plants. The cost of operating wood fired plants is also higher due to extra personnel and equipment required to maintain and operate the feed and ash recovery mechanisms.

In summary, this study showed that the utilization of logging residues is technically feasible. However, the apparently favorable economic value as a replacement fuel based on potential energy value are offset by substantially higher costs of converting this fuel to a useable energy source. This situation will improve as more cost-efficient methods of retrieving and processing logging residues are developed and as the price of alternative fuels increases.

CASE STUDIES FOR SWITCHING TO WOOD FUEL

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EXTENDED ABSTRACT

In all of the forested areas of our country, widespread interest is developing in the possible use of wood for fuel energy as a replacement for natural gas and oil. Plant engineers of nonforest associated industries face a considerable task in attempting to evaluate wood for a particular facility. How to determine the availability of wood for energy use, in what form is it available and at what cost? What types of combustion systems are necessary for wood, what emission controls are required? How do you design wood handling facilities, what area is required, what equipment is necessary?

To provide assistance in answering these questions, the Georgia Tech Engineering Experiment Station has just completed the first year of a project to stimulate the widespread use of wood in nonforest industries in Georgia. One task of this project investigated the technical and economic viability of wood energy through the preparation of fourteen industrial feasibility studies for potential users.

The feasibility study sites were carefully chosen to provide a broad base of information. The majority of the applications were for boilers and their sizes ranged from 2,650 lbs to 75,000 lbs of steam per hour. Two of the studies involved the direct application of combustion gases for product dryings. Industries represented were: textiles, poultry, mineral processing, and cordage manufacturing.

Each of the studies indicated that all applications considered were technically feasible and that sufficient wood fuel was available. In some instances, the quantity of wood waste material was limited and the wood fuel supply would depend upon whole tree chips. The economic studies indicated simple paybacks ranging from nine months to 8 years. Some of the significant factors that influenced economic payback were:

- Size of facility
- Percent utilization
- Cost of competing fuels -- oil, gas, and coal
- Hours of yearly operation

The savings resulting from the replacement of an existing gas only system with a wood system depend both upon system and its utilization factor. Savings associated with small size systems are usually not significant on a short term basis. However, on a long term basis the savings improve as a result of the escalation of natural gas prices. In larger systems, 400 hp and higher, the savings resulting

from the use of a wood system are significant. The savings and the payback period before taxes are especially attractive in cases where more than 25% of the existing energy consumption is provided by fuel oil. In those cases where the existing system uses natural gas only, the annual savings are moderate.

For coal fired systems, the existing small differential between the effective costs of wood fuel and coal make the return on investment associated with conversion not attractive at the present time. However, on a long term basis, as indicated by the table of life cycle costs, the savings increase. More in-depth studies concerning the design and costs of conversion in the case of coal fired boilers would be desirable.

The results show that the utilization of wood energy in nonforest industries is economically feasible at current prices of gas and oil.

The annual savings realized from the replacement of existing systems by wood systems are very attractive where gas and oil are currently being used. The savings are not attractive at the present time if coal is replaced by wood.

TRANSPORTATION FUELS FROM WOOD

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EXTENDED ABSTRACT

The production of oils and tars from wood and other organic materials (biomass) has been reported in the scientific literature for over a century. Interest in this topic has intensified recently because of the potential for generating liquid fuels from wood and waste materials including sewage sludge, municipal trash, or manure. At present, the approaches for producing liquid hydrocarbon products are of two primary types. First, the biomass source may be converted directly to liquid products which are subsequently used as produced or further refined. These direct liquefaction methods include thermochemical liquefaction, fermentation and pyrolysis. A second method of producing liquid hydrocarbons from biomass sources involves an indirect approach where biomass is first converted into a gaseous intermediate from which liquid fuels are then synthesized. Indirect methods of liquefaction include methanol synthesis, hydrocarbon synthesis via the Fischer-Tropsch reaction, gasoline via methanol, and gasoline from light olefins.

The largest obstacle to energy independence in the U.S. is the need for transportation fuels such as gasoline, diesel, and jet fuel. Because petroleum has been the only principal source of transportation fuels most engines are designed to use petroleum based fuels. Use of synthetic fuel from wood (or other sources) as transportation fuels will require one of the following:

- Refining and treating of synthetic fuels so they chemically resemble petroleum fuels.
- Engine modifications to allow fuels that differ chemically from petroleum to be used.
- Synthetic fuels, such as alcohols, can be blended with petroleum fuels and used with little or no engine modifications.

Ethanol can be produced from wood by hydrolysis followed by fermentation. The drawbacks to this technique are the inefficient conversion of the hemicellulose and lignin fractions of the wood and the energy intensive nature of the distillation process used to recover the ethanol. Advances in alcohol separation and recovery technology may improve the thermal efficiency of the process, however, production of liquid fuels from fermentation of wood is unlikely to be competitive with other

methods unless an efficient means to convert the hemicellulose and lignin fractions is developed.

Direct liquefaction processes, like the two processes being developed by The Department of Energy at the Albany, Oregon, process demonstration unit, have the potential to produce liquid fuels from wood for significantly less cost than other liquefaction techniques. Oils from both the PERC and LBL processes have a high specific gravity and a high oxygen content compared to petroleum. Studies are underway at PNL to provide a more complete characterization of the wood oil and evaluate means of upgrading the oil to more valuable products. Production of transportation fuels from this oil will involve extensive hydrogenation and cracking. PNL is arranging for testing of two different upgrading techniques. Plans are to look at a Union Oil process that will be used to convert creosote tars to diesel fuel. Creosote tars are chemically similar to wood oil and this process may be capable of converting wood oil to diesel type fuels also. In addition, Mobil shape selective catalysts will also be tested on the wood oil.

Production of liquid fuels by indirect liquefaction involves gasification to produce a synthesis gas followed by liquid fuels synthesis. Indirect liquefaction processes can be considered, for the most part, commercially proven. Only the large scale gasification of wood has to be proven and this should not present any serious difficulties. However, production of methanol from wood using current technology is capital intensive and the cost of methanol is 20-100 percent more expensive than gasoline in the U.S. on an equivalent Btu basis. Production of petroleum-like liquid fuels via the Fischer-Tropsch (F-T) process or the Mobil methanol-to-gasoline process is even more costly.

Traditionally oxygen-blown gasifiers have been used to produce synthesis gas from coal and the cost of the oxygen plant is a significant contributor to the overall capital cost. In addition, the H_2/CO ratio in the gas is about 1/1 while 2/1 is required for liquid fuels synthesis. As a result the gas must be shifted prior to synthesis.

Because wood is more reactive than coal it has the potential for gasification at lower temperatures possibly without the use of oxygen. PNL is developing a catalytic steam gasification process aimed at direct conversion of wood to specific gas products, one of which is methanol or hydrocarbon synthesis gas. A synthesis gas with a H_2/CO ratio of 2/1 has been produced in a laboratory scale reactor using a nickel catalyst and silica alumina catalyst at 750°C and atmospheric pressure. Currently a fluid bed process demonstration unit is being operated in an attempt to obtain similar results on a larger scale. A feasibility study of commercial size methanol facility based on PNL's gasification system has just been completed by Davy McKee Inc.

The Fischer-Tropsch process is used commercially in South Africa to produce petroleum-like fuels from synthesis gas. On the small scale of

wood based plants (probably < 1000 barrels per day) the F-T process suffers significant economic penalties because of the wide range of fuels produced. What is essentially a refinery is required downstream of the synthesis to separate and upgrade the various products. Laboratory scale studies at PNL are directed at improving the economics of liquid fuels production from wood via the F-T process. This involves improving the selectivity of the process by using various combinations of F-T catalysts and zeolite catalysts, and integrating the process with advanced biomass gasification processes.

A WOOD GASIFICATION DEMONSTRATION PROJECT
FOR THE NORTHWEST GEORGIA REGIONAL HOSPITAL

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EXTENDED ABSTRACT

INTRODUCTION

The Georgia Forestry Commission and the Georgia Tech Engineering Experiment Station have been cooperating on a number of wood energy projects since 1977. In 1978, it was decided that a demonstration of an emerging technology should be carried out at a state facility, where maximum benefit of alternate energy use to the state's taxpayers could be realized.

Georgia Tech personnel and Georgia Forestry Commission personnel visited a number of sites where wood gasification systems were being run, as well as other state-of-the-art systems such as wood burning fluidized beds. After these systems were examined, it was decided that a specification would be written to obtain a retrofit wood gasification or pyrolysis system for one of the 550 horsepower boilers at the Northwest Georgia Regional Hospital in Rome, Georgia. This project would enable the hospital to reduce its dependence on No. 6 fuel oil and natural gas. The major goal was a demonstration of a near-commercial wood fired system that could be expected to operate in a semi-automatic mode for at least 3,000 hours per year. A bid package was sent out to fifteen prospective companies and the vendor selected to build the system was Applied Engineering Company (APCO) in Orangeburg, South Carolina.

FUEL SUPPLY

A major goal of the demonstration project is the successful gasification of green wood chips to produce low Btu gas for a boiler application. In preparation for the project, the Georgia Forestry Commission has stockpiled more than 1,500 tons of wood chips at the hospital site to be used as fuel. These chips have been stored in the open and have been part of a storage method study being carried out by the Georgia Forestry Commission. The chips are mixed hardwoods and softwoods produced by a total tree chipping operation in the area. Present cost of this material is approximately \$14.50 per ton delivered to the hospital. Sawmill residue has been avoided due to the high content of fine particles which may not be amenable to operation of the wood gasifier. However, after the startup of the system, it is

anticipated that various forms of fuel (different moisture contents and species) will be tried.

SYSTEM DESCRIPTION

The existing steam plant has three watertube boilers burning gas and oil. The steam produced is used for space heating on the hospital grounds and for the hospital laundry. In addition, steam is used in the summer to run two absorption air conditioning machines. It is rarely necessary to have more than 1.5 times the capacity of one boiler available for steam production, so there is always one unit on standby.

The gasifier vessel has been sited outside the steam plant in the open air. Low Btu gas is piped to the boiler burner in a large insulated pipe approximately 80 feet in length. The gasifier has its own air supply and control system. Chip delivery will be accomplished with a truck dump and a live bottom receiving pit. The chips will be transported from the pit to a 3½ day storage silo by chain conveyor. The silo will be equipped with a reclaim system for supply of chips to the gasifier itself. Full startup is slated for October 1980.

SYSTEM ECONOMICS

The total price of the system will be in the range of \$350,000 to \$400,000 and payback periods will be between 1.5 and 5 years depending on assumptions about the mix of natural gas and fuel oil that will be replaced. After several months of operation, the economics of the system will be more fully understood.

FUTURE PLANS

It is anticipated that there will be some problem areas uncovered during and after full scale startup. During the first year of operation, these problem areas will be corrected and meaningful data on economics and system emissions will be collected.

ECONOMIC ASPECTS OF LOW-TEMPERATURE POWER INSTALLATIONS

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EXTENDED ABSTRACT

INTRODUCTION

Taking into account the limited world primary energy sources, the problem of energy supply for industrial enterprises will probably grow in importance. One of the possible way to increase the efficiency of fuel utilization is the usage of low-temperature energy sources (370-420 K), wasted by industry to the environment.

OBJECT OF INVESTIGATION AND PROBLEM FORMULATION

In 1965 an experimental low-temperature installation for electric power generation using Freon-12 (R-12) as a working body, was elaborated and put into operation at the Institute of Thermophysics in collaboration with several other Soviet organizations. Test examinations at the Shatura power station and further service tests at the Paratunka Geothermal Electric Station showed that a reliable efficient power installation had been elaborated. In terms of the systematic approach, a mathematical model of low-temperature power installation utilizing low-boiling substances has been developed at the Institute. As a criterion function, the given calculated investments, I , were taken accounting for the influence of both external and internal relations between the parameters of the object under modelling. The structure of the above model in combination with the methods of determination of the minimum criterion function permits us to elucidate the totality of optimal parameters and structural-component characteristics ensuring the greatest economic efficiency of the above installation. The object of the present study was a low-temperature power installation utilizing wasted low-temperature heat with Freon-21 as a working body.

RESULTS AND DISCUSSION

Complex thermodynamic and technico-economic studies were performed for various climatic conditions in the Soviet Union. Ten independent parameters have been found exerting the greatest influence on the criterion function variation.

They are: initial pressure of freon vapour in front of turbine, temperature of superheated freon vapour, final pressure of expansion process, temperature difference on a hot end of condenser, cooling water velocity in condenser tubes, velocity of primary heat carrier in heating, boiling and superheating region and freon velocities in freon vapour generator.

OPTIMIZATION

The problem of calculation of the optimum parameters of the freon power installations was formulated as the definition of the minimum criterion function

$$\min I = I [X, Y(X)]_{E_0} \quad (1)$$

with nonlinear limitations in the form of equalities

$$F [X, Y(X)]_{E_0} = 0 \quad (2)$$

and inequalities

$$S^* \leq Y [X, Y(X)]_{E_0} \leq S^{**} \quad (3)$$

by the direct Gauss-Seidel optimization method.

CONCLUSION

The main results of the technico-economic optimization at the nondeterminate specification of the initial data indicate the economic efficiency of the above low-temperature installations utilizing wasted low-temperature energy carriers (warmer, saturated water vapours). One of the promising field of their application can be various systems of evaporative cooling for industrial enterprises.

NOMENCLATURE

- X - totality of independent installation parameters under optimization
- Y(X) - totality of dependent parameters
- E_0 - external influencing factors

AN ECONOMIC PLANNING TOOL FOR GEOTHERMAL ENERGY PROJECTS

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EXTENDED ABSTRACT

PROGRAM OBJECTIVE

The goal of the Sandia Laboratories' Geothermal Well Technology Drilling and Completion Program is to reduce significantly the cost of drilling geothermal wells. The rationale behind this goal implies that reduced drilling costs will promote the development of geothermal resources and reduce the demand for fossil fuels. This occurs by increasing the profitability of geothermal energy through reduced costs without attendant decreases in the price of the geothermal resource.

The principal objective of the study is to derive a set of cost estimates from which one could determine the effect of reduced drilling costs on the costs of heat for direct applications of geothermal energy. Three projects were selected for analysis. The Holly Sugar Company Project is representative of a large process heat project with a single industrial user of a high grade geothermal resource developed by a resource company. The Philip School project uses a single well and a low grade geothermal resource developed by a local public agency and used in cooperation with local businesses. The El Centro project uses a moderate grade geothermal resource for both heating and cooling of residential and industrial sectors.

GEOCITY MODEL AND PRINCIPAL INPUTS

To derive cost estimates, this study utilized the GEOCITY computer simulation model. GEOCITY simulates the entire production, distribution, and waste disposal process for geothermal heating systems, in which distribution implies delivery of a quantity of energy to the direct user. It can be used for both space and process heating.

GEOCITY is composed of two principal parts: (1) a geothermal reservoir submodel, and (2) a distribution system submodel. The reservoir submodel calculates the cost of energy by simulating the exploration, development, and operation of a geothermal resource from the identification of potential sites through the economic life of the distribution system. GEOCITY utilizes present value techniques to equate expected revenues and costs including the cost of capital under any combination of debt and equity structure. The GEOCITY model uses cost estimating factors based on 1976 dollars, and requires corresponding inputs and outputs.

A model of this complexity requires a large number of input variables to project site-specific cost estimates. All input variables have default

values, and in many instances these default values were used. Site-specific variables related to either reservoir or distribution characteristics and economic values.

A preliminary sensitivity analysis was performed on many of the input variables using the Holly Sugar project as a test case. Since some variable effects were found to be insignificant and assumed to be similarly insignificant for other projects, these input variables were fixed throughout the study.

SUMMARY OF RESULTS

For each project, a set of resource characteristics and system inputs were chosen to represent a baseline condition which could likely exist at each specific site. The estimated cost of heat for the baseline case was calculated along with other cost estimates representing possible optimistic and pessimistic conditions.

In order to assess directly the impact of reduced drilling costs upon the cost of heat, regression equations were developed for each application to relate quantitatively changes in the input variables (flowrate, temperature, well cost, etc.) to changes in the cost of heat. The equations represent (very well) the individual projects in relation to cost, and provide a means to achieve the program objectives.

Using the equations with baseline values as inputs, a 25-percent reduction in drilling costs provides a:

- 12 percent reduction in heat costs for Holly Sugar.
- 8 percent reduction in heat costs for Philip School.
- 6 percent reduction in heat costs for El Centro.

The regression equations also provide a means to point out the principal cost drivers through examination of the data. Table 1 lists the principal cost drivers in terms of relative importance. Brackets indicate rankings between which the differences are insignificant.

TABLE 1. PRINCIPAL COST DRIVERS

<u>Holly Sugar</u>	<u>Philips School</u>	<u>El Centro</u>
Load	Peak Demand/Load	Load
Cost of Capital	Average Project Life	Temperature
Flowrate	Well Costs	Usage Density
Well Costs	Well Costs x Project Life	Peak Demand
Temperature		Cost of Capital
		Flowrate
		Well Cost

Some of the variables cited above can be combined to assist in better understanding of the listings. It seems reasonable to combine those

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variables which determine the cost of the well field. If this were done, the principal cost drivers relating to all of the projects would rank as:

- (1) Percent load
- (2) Factors determining the cost of the well field
- (3) Cost of capital.

On the basis of the projects examined in this study, reduced well costs, including drilling and completion, will have a significant effect upon the rate of commercialization of direct heat geothermal energy.

ENTROPY PRODUCTION IN GEOTHERMAL POWER PLANTS

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EXTENDED ABSTRACT

INTRODUCTION

Geothermal energy, although a curiosity twenty years ago, has now become a viable solution to the energy shortage. In the United States alone the capacity of geothermal power plants has risen to 1200 MW-e and the projected capacity until 1985 is 3500 MW-e. These plants are classified in four broad categories according to the way of exploitation of the geothermal resource: single-flash, dual-flash, binary and hybrid [1].

This paper analyses the geothermal power plants according to their capacity of converting the exergy of the brines into useful work. The estimation of the entropy production at all the processes in the plants provides us with a measure of the dissipated work. This in turn yields the utilization factor for the plant (a term analogous to the "second-law efficiency") [2].

Assessing the geothermal installation according to the above (exergy) analysis will give us the thermodynamically advantageous plant for the utilization of the geothermal resource, that is the one which will yield the maximum amount of work from a given quantity of geothermal fluid. A thermodynamic and an economic analysis of the plant will determine its feasibility of success in the market place.

ANALYSIS

All geothermal power plants are viewed as open systems in contact with a constant temperature heat reservoir (atmosphere). The input to the system is the energy rate of the geothermal fluid and the output the useful and dissipated power (since there is no further utilization of the exergy of the outgoing fluids it is assumed that it is dissipated in the plant). A schematic diagram of the system is shown in Fig. 1.

The dissipated work in the plant is calculated from the amount of entropy production. For that matter, all the processes in the system are analysed and the entropy production in them is calculated. The utilization factor of the plant is then

$$\eta_u = 1 - T_o \frac{\Sigma \dot{\theta}}{\dot{E}_1}$$

where $\Sigma \dot{\theta}$ is the total rate entropy production, $\dot{E}_1$ is the rate of exergy coming into the plant and T_o is the ambient temperature. The total rate of dissipated work is $T_o \cdot \Sigma \dot{\theta}$.

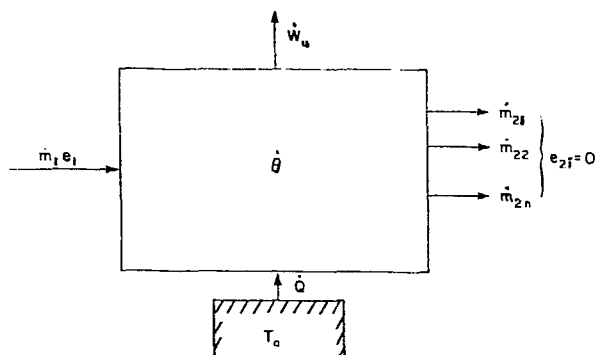


Figure 1.

This novel approach to the problem of utilization of geothermal resources through the entropy production has two main advantages:

- 1) It yields immediately the utilization factor of a given plant; this factor is the best criterion for the assessment of the conversion of the brine's energy into useful work [3]. Thus, the plants can be classified according to their capability for energy conversion.
- 2) The calculation of the entropy production in each process reveals the processes where exergy is wasted. This fact leads the engineer to the improvement of these processes or the use of different ones.

RESULTS

The utilization factors of the geothermal plants are calculated as functions of the resource temperature. It is concluded that the geothermal resource is better utilized in the hybrid/preheat plants, while the more simple and least expensive single-flash units give poor utilization factors.

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INVESTIGATION OF A TWO-PLATFORM HINGED WAVE ENERGY POWER CONVERTER

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EXTENDED ABSTRACT

INTRODUCTION

Wave energy, though abundant in supply, exists in low concentrations, varying amounts and varying frequencies. It is a challenge to extract this dispersed energy by an economical means. For best economy, it is, therefore, necessary to extract the power as efficiently as possible, but with minimum capital and maintenance costs. The highest efficiency for a realistic wave climate is obtained using a model that can be tuned to the frequency of the predominant incoming waves.

The wave energy team at the Technical University of Nova Scotia examined the alternative mechanisms for extracting power from the waves and chose to study a two-platform wave energy power converter for simplicity in concept, low capital cost, one that can be tuned to the different wave frequencies, and one which can be modelled both physically and numerically. The paper will describe the results of wave tank tests on the third model, 1.5 m wide by approximately 5 m long. Computer model analysis will be used to complement the physical data.

PHYSICAL MODEL AND DATA ACQUISITION

The physical model has two platforms hinged together. As a wave passes by, the platforms oscillate relative to each other, driving a hydraulic pump mounted on the hinge. Each platform has two moveable floats, as well as a moveable weight. The magnitude and location of the moveable weights can vary the natural frequency of two-hinged platform system. Tests have been run for different platform parameters. The platform in its normal configuration is shown in Fig. 1. A metal sheet was also placed under and between moveable floats. The metal sheets or skirts slid in grooves when the floats were moved. For other tests, foam inserts were placed in between the floats. In an attempt to increase efficiency, dampers were attached to the rear of the trailing platform. Also, vertical plates were attached to the rear of the second float of each platform in order to determine, if, by this simple means, some of the kinetic energy in the wave can be extracted as well as the potential energy.

The model has been tested in the 5 meter wide wave tank at the National Research Council Hydraulics Laboratory in Ottawa, Canada, for both regular and irregular waves. Wave probes ahead and behind the model were used to obtain the wave height for both the forward and reflected waves.

All data was recorded on an on-line EAI computer using 12 bit A-D converter sampling at 10 hertz. Measurements of torque on the hinge and relative angular position between the two floats, hydraulic pressure and flow were used to obtain the magnitude of power both at the hinge and in the hydraulic loading system. (The data of relative angular position between the two platforms was analyzed using a Fast Fourier Transform, smoothed and differentiated to yield angular velocity.)

COMPUTER MODEL OF DYNAMIC MOTION

The computer model that has been developed is a spring-mass damper system with base excitation. The spring force is the buoyancy force, and the forcing function is due to the waves. The added mass function which is both discontinuous and frequency dependent is very complicated to analyze for the concave bottom shape that is used in the physical model. As a first approximation, a flat float bottom is assumed and the added mass is determined in the computer model by utilization of the Frank Close Fit Method.

COMPUTER MODEL OF HYDRAULIC SYSTEM

A numerical model of the hydraulic system on this hinged platform and on a proposed larger hinged platform has been made in order to ascertain the optimal system for obtaining steady flow from the rectified sinewave input produced by the rotary actuator on the hinge. The computer model responses showed excellent agreement with the experimental data obtained from the physical model.

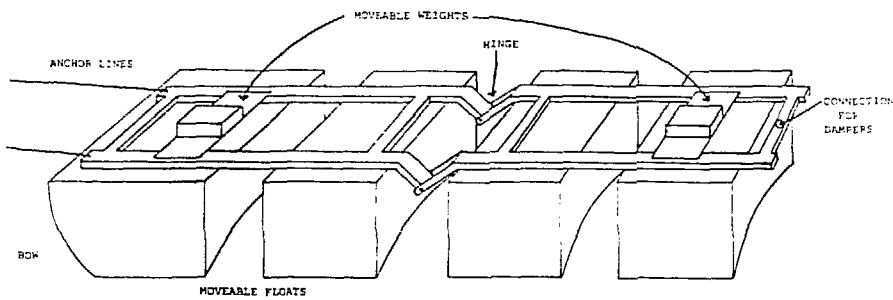
RESULTS

Some test results are shown in Fig. 2, where some parameters are adjusted. Most data was obtained for regular waves, although some data has also been obtained on waves of broad and narrow spectrum and will be included in the presentation. The wave height and length is maintained constant, and the length of platform is varied to demonstrate the effect of tuning this type of wave energy converter to the wave length. The questions that this paper seeks to answer are:

1. What length of platform to wave length is best for extraction of power for two-platform wave energy converters?
2. Is there a critical mass that tunes the platforms to the natural frequencies of the incoming waves, and can the natural frequency of the platforms be varied by adjusting the location of the center of mass of the platforms?
3. Do skirts under the platforms have any effect (positive or negative) on the operation of a two-platform wave energy converter?

4. How much power is gained if the space between the buoyancy chambers is filled with foam, and does its increase warrant the loss in adjustability? What is the cause of the increased power?
5. Is there some simple means to extract some of the kinetic energy in addition to the potential energy in the waves?

These and other questions are discussed more fully in the paper.



A Hydraulic Actuator (not shown) converts the relative motion of the two rafts into useable energy.

Fig. 1. Schematic of Wave Energy Converter

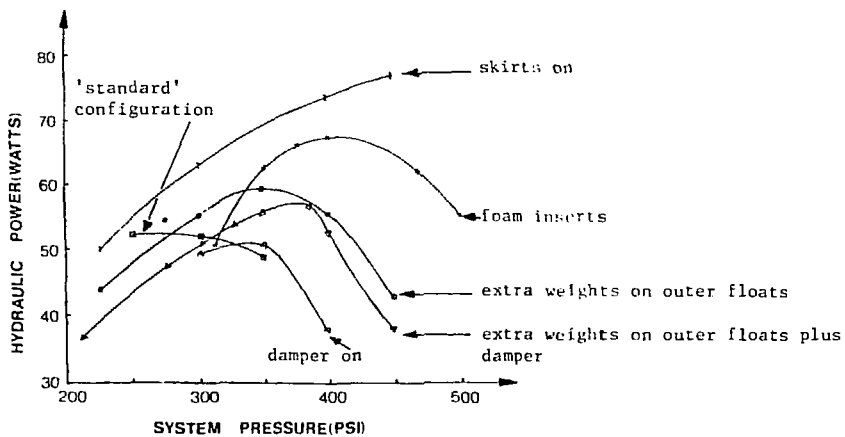


Fig. 2. Sample of Hydraulic Data for some Parameters

CONCENTRATION CELL FOR SALINITY POWER PRODUCTION
Economic potential of the concentration cell

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EXTENDED ABSTRACT

INTRODUCTION

The free energy available in the process of mixing river water and sea water is about 2.5 kJ/kg river water if unlimited quantities of sea water can be used. In practice only some part of this energy can be used. The most direct way of transforming salinity power into electricity is by using concentration cells. It has been estimated /1/ that a membrane battery using crossed water flows could possibly produce electricity at a cost of 0.05 \$/kWh. To make this possible, however, several improvements in membrane technology have to be made.

The selectivity has to be at least 90% and the area resistance $0.2 \Omega \text{cm}^2$ or less. Further the membrane separation has to be between 0.1 and 0.15 mm. The corresponding figures for the laboratory batteries used today are 65%, $10 \Omega \text{cm}^2$ and 0.25 mm respectively.

MEMBRANE PROPERTIES

The voltage across an ion exchanging membrane separating two NaCl-solutions of slightly different concentrations is given by

$$(1) E_o = \frac{\alpha R T}{F} \ln \frac{a_1}{a_2}$$

Here E_o is the electromotive force, R the gas constant and a the NaCl activities of the two solutions. α is the selectivity of the membrane. If α is known at one salt concentration it can be approximated at another by the expression

$$(2) \ a_2 = \frac{c_1 a_1}{(c_1^2 a_1^2 + c_2^2 (1 - a_1^2))^{1/2}}$$

In this expression c is the concentrations of NaCl and the indices refer to the two solutions.

The area resistances of the membranes vary only slightly for NaCl concentrations between 0 and 2 N.

Selectivities and area resistances have been measured /2/ for some commercially available membranes as well as for some new kinds. Selectivity values have been found to range from 55% up to more than 90%. The measured area resistances have been between 0.3 and 10 Ωcm^2 .

CELL WITH COMMERCIALY AVAILABLE MEMBRANES

In a study of a test stack containing 52 membranes /3/ an efficiency of about 25% has been measured in solutions containing 0.6 and 3.0 percent NaCl. The efficiency here is defined by a comparing the measured power output with that calculated from salinities, resistances and selectivities. The measured efficiencies are smaller than those found by Leitz and Weinstein /4/. The reason is probably that a crossed flow battery is much more sensitive to water leakage than the conventional stack design used in electrodialysis.

The measured battery properties have been used together with earlier estimated costs /1/ for the equipment needed outside the batteries to make a salinity power station work. For the case of brine containing 18% NaCl in combination with brackish water containing 0.2% NaCl the power cost would be about 4 \$/kWh. In the case of sea water and river water, the energy cost would be slightly lower, or about 3 \$/kWh. The explanation of this apparent contradiction is mainly the decrease in selectivity at high salinity values. Thus in this case, the more concentrated source of energy gives a greater cost.

IMAGINED CELL USING NEW KINDS OF MEMBRANES.

The best selectivity values found /2/ among the the membranes studied are 98% for cation selective and 92% for anion selective membranes. At 18% salinity, this would correspond to 94% and 80%. These two samples had rather great area resistances, about 1 Ωcm^2 . A battery using such membranes would produce electricity at a cost of 0.17 \$/kWh.

If energy is produced from river water and sea water, the most essential property of the membrane is the area resistance. The lowest values measured are $0.33 \Omega \text{ cm}^2$ for an anion membrane and $0.56 \Omega \text{ cm}^2$ for a cation membrane. These membranes had both selectivities of about 77%. The figures result in an energy cost of 0.28 \$/kWh.

CONCLUSION

One of the main costs behind the figures above is that of the spacers separating the membranes from each other. None of the membranes studied up to now can be manufactured together with the spacers. Otherwise, the properties are rather close to those discussed in Miami 1977 /1/. If such a modification could be made, the energy cost would drop to 0.05 \$/kWh for river water/sea water and to about 0.013 \$/kWh for 18% brine.

To reach these low costs, one would have to produce batteries in very large quantities. Forgacs and O'Brien /5/ have estimated the costs under similar circumstances to be 0.10 \$/kWh and 0.02-0.05 \$/kWh respectively.

Still many problems concerning the membranes remain to be solved. Examples of such problems are membrane swelling and the chemical stability of the membranes.

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ANALYSIS OF REVERSE VAPOR COMPRESSION SYSTEM INVOLVING SALT RECYCLING

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ABSTRACT

Salinity power utilizes as "fuel" a pair of brines, one dilute and one concentrated. Brine mixing is accomplished in such a way that an appreciable fraction of the free energy of mixing is converted into useful energy. Three different methods of accomplishing this have been proposed. Two such methods involve the use of membrane permeators. In Osmo-Hydro Power™ (OHP) systems, semipermeable or osmotic membranes are utilized in the pressure-retarded osmosis mode to produce pressurized brine, from which power is obtained by depressurization through a hydroturbine. In Reverse Electrodialysis (RED), electric power is produced directly due to the transport of ions through ion-exchange membranes permeable to either cation or anions. The third method, called Reverse Vapor Compression (RVC) system, utilizes the vapor pressure difference between the dilute and concentrated brine directly to run a vapor turbine.

The objectives of this paper are i) to present the results of a study on the analysis of salt-recycle RVC systems, ii) to compare the results of this study with other studies in the past and with other salinity power systems using membranes. Salient features of RVC systems in comparison to the membrane systems will also be outlined.

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SESSION 2D

NUCLEAR ENERGY I (FISSION)

ABSTRACT

The High Temperature Gas-Cooled Reactor
A Flexible Energy Option

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Introduction

Recent activities by OPEC, the political activity and uncertainty in the Middle East, and the spiraling energy costs and depleting oil and gas energy reserves in the U.S., have all helped to sharply increase interest among utility and industrial energy users in the High Temperature Gas-Cooled Reactor (HTGR) as a flexible heat source. This reactor system, due to its inherent design features, can provide steam or process heat at conditions beyond the capability of current generation light water reactors. This expanded capability enables nuclear heat to be applied to energy sectors other than pure electricity generation (Figure 1), where nuclear currently provides only about 4% of total electrical capacity. The HTGR can provide this flexibility while maintaining the key safety, operational, and environmental advantages of the basic HTGR System.

The HTGR nuclear heat source (Figure 2) which is common to all HTGR-based systems is a helium-cooled reactor consisting of an all-ceramic nuclear fuel and core structure enclosed within a prestressed concrete reactor vessel (PCRV). Advantages of this system are based on the low power density of the core, the high temperature capability and large number of the reactor core and core support structure, and the structural integrity and redundancy of the PCRV. The applications of this nuclear heat source can be fashioned around discreet ranges of the outlet temperature conditions of the reactor core.

HTGR-Steam Electric/Cogeneration

In all HTGR Systems, helium gas is used as the coolant to remove the heat from the core. In the HTGR-Steam/Electric Cogeneration System the helium is heated to 750-800°C. This heat is transferred in a heat exchanger to generate steam for process use and electricity production. The entire primary system including steam generator, helium circulators, and auxiliary heat exchangers are housed within the thickwalled PCRV. The uranium-thorium fuel is contained in table height hexagonal graphite blocks, several thousand of which make up the reactor core. Because of the high temperatures, superheated steam can be produced, contributing to the thermal efficiency of about 40%, the highest of any nuclear plant. The superheated steam conditions allow application of this HTGR heat source to industrial processes not available to current generation reactors. These processes include;

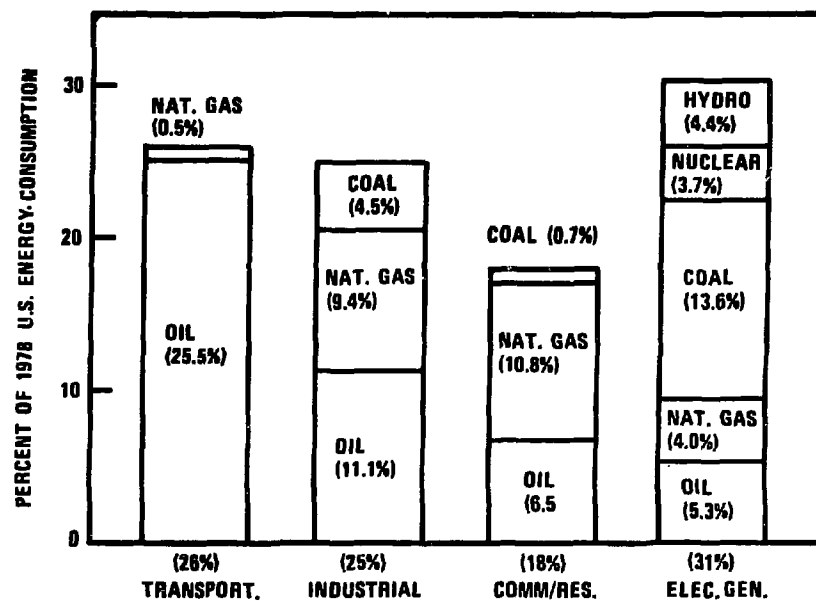


Figure 1. Energy Sectors

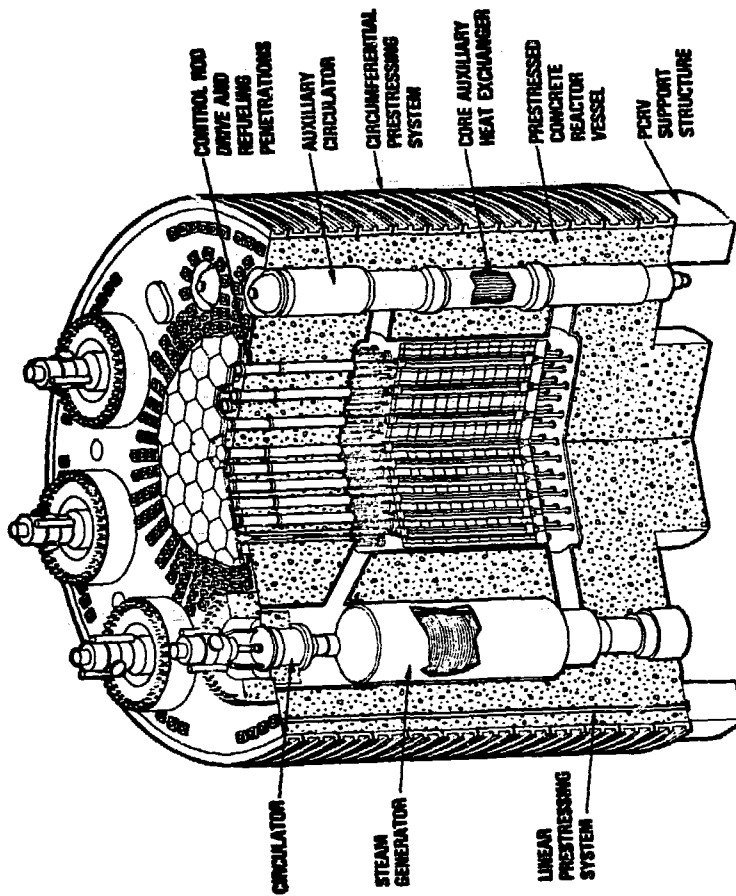


Figure 2. HTGR Nuclear Heat Source

- Chemical, petrochemical, steel mill, paper mill processes
- Shale oil recovery via steam retort
- Oil recovery from tar sands or heavy oil
- Desalination

HTGR-Gas Turbine Electric/Cogeneration

This system uses the same basic HTGR technology. Except that the helium, in addition to being used as the coolant, is also used as the working fluid with an integrated gas turbine. Helium core outlet temperatures are higher, in the 800-850°C range. With the gas turbine, a "Brayton" cycle is used which, in addition to high thermal efficiency, results in a high heat rejection temperature (150°C). This results in the economic application of dry cooling for "waterless" electric power generation. As an alternate, this high reject heat can be used in a "bottoming" cycle to achieve efficiencies of 50% or for cogeneration of process steam.

HTGR-Process Heat

The HTGR-PH utilizes the same basic technology as other HTGR systems, but is based on a higher range of helium core outlet temperatures of 800-1000°C. This reactor is thus the only fission reactor that appears to be able to directly provide energy for high-temperature processes at these temperatures, thus expanding the application of nuclear energy to processes now served exclusively by fossil fuels. The heat is suitable for use in hydrogen and synfuel production using coal, residual oil, or oil shale as the carbon source. It can serve as a heat source for thermochemical water splitting processes, or in large scale energy transport and storage systems for industrial or utility use. Potential users include:

- Coal gasification via steam-methane reforming
- Syngas or H₂ production from coal
- Coal liquifaction processes
- Thermo-chemical heat pipe for energy storage/transmission
- Oil recovery from above ground or in situ oil shale
- Reducing gas production for steelmaking
- Methanol or Ammonia production
- Thermo-chemical Water Splitting

Current Program

The current HTGR program is a cooperative effort among the utility and industrial users, the supply industry, the U.S. government, and parallel foreign programs. Emphasis has been placed on early user involvement in the development programs, and two user groups have been formed -- Gas-Cooled Reactor Associates and the Process Heat User Group. It is the basis of the current program that planning be directed toward a first plant demonstration step involving one of the alternative HTGR systems described in this paper.

FAST BREEDER REACTORS AND
PLUTONIUM FUEL SUPPLY

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EXTENDED ABSTRACT

The primary incentive for the development of nuclear power is that nuclear energy offers an attractive partial replacement for our dwindling petroleum resources. A replacement, incidentally, that is not clouded by CO₂ and acid rain environmental concerns. Our nuclear resources, however, are only comparable to our petroleum resources if we do not develop more advanced reactors than the current light water reactors (LWRs). Fast breeder reactors (FBRs) offer a 50- to 100-fold extension in our nuclear energy resources.

The above arguments for reactor development have been well understood since the early days of atomic energy. However, there are two other considerations related to FBR development that are not as widely recognized. First, FBRs are in several respects a more simple and flexible reactor than LWRs, and these characteristics may turn out to be as important an incentive for development as resource utilization. And second, although FBRs breed excess fuel (plutonium), they do it at a relatively slow rate, and require a substantial initial supply of plutonium for operation.

Sodium cooled fast breeder designs potentially contain several simplifying features. For example, fuel life is not constrained by reactivity limitations, thus allowing longer fuel life and less poison control. In addition, since the coolant is not pressurized, and virtually cannot escape to uncover the fuel, the complex arrangement of low and high pressure injection systems present in LWRs are not required in FBRs. Such simplifications could lead to better safety and reliability, easier operation, and lower capital cost.

An initial plutonium supply is not essential for breeder startup. Indeed, many of the early FBRs were fueled with U-235--e.g., EBR-I, EBR-II, Dounreay, FERMI, and virtually all the Russian fast reactors. Nevertheless, Pu-239 is neutronically superior to U-235 as a fast reactor fuel--the uranium critical mass is about 30% greater than the plutonium critical mass resulting in higher fuel production rates and Doppler safety coefficients for plutonium fueled breeders. But even more important, plutonium is the only logical long-term fuel for breeders. And its use in this connection is a natural evolution of the use of low-enriched uranium in LWRs since LWR spent fuel contains an appreciable fraction (0.5-0.6%) of fissile plutonium.

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Nuclear fission energy is needed to help alleviate our dependence on dwindling oil supplies, and breeder reactors can serve to extend our nuclear resources to the point of providing abundant electrical energy for at least the next century. In addition, fast breeder reactors are in several ways simpler in basic design than current water reactors, and offer a more flexible fuel cycle. In order to achieve these potentials, however, reactor spent fuel must be reprocessed and recycled into breeders.

LIQUID METAL FAST BREEDER
REACTOR SAFETY IN LIGHT OF THE
THREE MILE ISLAND INCIDENT

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The safety aspects of the Liquid Metal Fast Breeder Reactor (LMFBR) loop design are compared with those of the Light Water Reactor (LWR), in light of the Three Mile Island (TMI) incident. The events at TMI are briefly described, the fundamental differences between the LWR water coolant and the LMFBR sodium coolant is presented, and how the analogous LMFBR safety systems are designed to act under similar events as those at TMI is discussed.

In the TMI event, the reactor shutdown systems properly responded. Therefore, the event has been categorized by various investigatory bodies as strictly a coolant behavior-related accident, compounded by active component failure and operator error, with no violent reactor kinetics involved.

To better understand the relationship of LMFBR system response with respect to that of an LWR involved in an incident similar to TMI-2, it is first necessary to briefly review the chronology of events that resulted in: (1) a pressure transient and subsequent discharge of primary coolant to the containment building, (2) loss of reactor coolant system pressure control and formation of a steam bubble in the reactor core, and (3) partial core damage with release of fission products to the reactor containment.

At approximately 4:00 a.m. on March 28, 1979, a loss of feedwater flow occurred with the reactor operating at 98% reactor power. As expected in such a situation, the resultant increase in primary coolant temperatures caused an insurge into the system pressurizer with a corresponding increase in primary system pressure. This pressure surge opened the electromagnetic relief valve and subsequently tripped the reactor on high coolant pressure. At this point all systems had functioned properly. However, as pressure decreased into the normal operating range, the electromagnetic relief valve failed to close and pressure continued to rapidly fall. Steam formation began in the reactor coolant system when pressure dropped to the saturation point. Core damage occurred releasing fission products into

the reactor coolant system and via the open relief valve into the containment building (by this time the rupture disc in the reactor drain tank had blown on overpressure and contaminated water was spilling onto the reactor containment floor).

The LMFBR heat transport system design can be characterized as a low pressure sodium system (<30 psig), while the LWR as a high pressure water system (~2250 psig). In addition, the LMFBR operating sodium temperature is well below the boiling temperature ($\Delta T=600^{\circ}\text{F}$), compared with the LWR water boiling temperature ($\Delta T=50^{\circ}$ to 100°F). Thus, the LMFBR has a much better intrinsic stability against a rapid Thermal Transient than the LWR.

A qualitative evaluation of a TMI-equivalent event for a LMFBR requires a comparison of LMFBR and LWR systems and how those systems react subsequent to a loss of feedwater flow at full reactor power. First, an LMFBR will trip immediately upon loss of feedwater and the resultant pressure transient in the reactor coolant system is almost negligible. A pressurizer and relief system is not necessary and expanding sodium, a result of the thermal transient, is simply overflowed from the reactor vessel to a large overflow vessel in the containment. The overflow vessel and related piping systems then serves as a source of makeup and decay heat removal for the primary system. It is important to note that an external coolant injection system is not required and that the overflow and makeup is a fully closed loop system. At no time is the primary coolant boundary integrity challenged, as was the case at TMI. In addition, the LMFBR normally operates with a sodium level in the reactor vessel, and level probes provide the operators with direct indication of sodium level at all times.

Second, the LMFBR Direct Heat Removal System (DHRS) is capable of removing heat from the reactor at any time following plant shutdown, should the auxiliary feedwater be inadvertently isolated from the steam generating system, and unlike the Decay Heat Removal System (DHRS) of an LWR, does not require any primary system depressurization for initiation. Finally, since a violent thermal and pressure transient does not occur and since the reactor coolant boundary is not breached following the events examined, such an incident would have been confined to a total loss of feedwater emergency condition, without core damage, release of fission products to the primary coolant and subsequent release of radioactivity to the reactor containment.

EVALUATION OF THE SLSF P2 LOSS-OF-FLOW
SAFETY EXPERIMENT

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EXTENDED ABSTRACT

INTRODUCTION

An in-reactor safety experiment (P2) was performed in the Sodium Loop Safety Facility (SLSF) with a 19-pin mixed-oxide fuel bundle that simulated a fast-reactor loss-of-flow (LOF) accident. An extended test duration of 21 seconds (consisting of a planned sodium flow coastdown) was provided to investigate fuel dispersion phenomena and possible upper metal-blockage relocation postulated to occur during the later stages of LOF accidents. Specific experimental information which was sought included the following:

- . location and time of boiling initiation,
- . coolant voiding and reentry dynamics,
- . timing and nature of cladding failure and fission gas release,
- . timing and nature of initial fuel motion (whether slumping or dispersive),
- . nature and extent of blockage relocation and fuel dispersal, and
- . coolability of the final test configuration.

EXPERIMENT DESIGN AND OPERATION

When inserted into the Engineering Test Reactor (ETR) at the Idaho National Engineering Laboratory, the SLSF loop is capable of providing a test sub-assembly with a thermal, hydraulic, and neutronic environment which simulates that within a fast reactor during postulated accident conditions. In addition, the loop can operate at full-power, steady-state conditions for extended periods as required for the pre-irradiation and restructuring of the fuel.

The main components of the self-contained SLSF loop are (1) the test sub-assembly, (2) the annular linear-induction circulating pump, and (3) a sodium-to-helium heat exchanger which provides loop heat removal. Approximately one-third of the loop flow passes through the test section; the

remaining two-thirds flows through an annular, orificed bypass which provides for continuous loop flow during tests in which the subassembly becomes blocked. A cadmium filter for hardening the neutron flux spectrum is bonded to the outer vessel of the doubly contained loop.

The fuel bundle and the SLSF sodium-cooled, in-reactor loop were highly instrumented to collect information on the continuing safe operation of the loop and information for immediate conduct of the experiment, as well as to gather experimental data needed for the analysis of the test results.

The pretest operation of the loop consisted of checks of loop component and instrumentation performance and an equivalent 24 days of full-power fuel irradiation. In addition a 24-hour period of continuous operation prior to the test was provided for fuel conditioning.

POSTTEST EXAMINATION

The in-reactor sensor data were supplemented by information obtained from a detailed posttest examination of the SLSF test train and loop including neutron radiography, gamma scanning, macrosectioning and visual examination, and detailed microscopic examination of metal blockages, fuel bundle components, and dispersed fuel accumulations.

The posttest examination evaluated the nature and location of cladding failure, relocation, and extent of blockage formation. The amount of fuel melting and dispersion as well as interaction of the molten fuel with bundle components were investigated. A detailed microscopic examination determined that the original upper blockage (formed from molten cladding) became disrupted and re-formed at a higher elevation within the bundle during the disturbance observed at the time of scram. A scenario of the progression of experimental events were deduced primarily from sensor data, posttest analysis, and the postmortem examination data and is presented in Table I.

TABLE I
OBSERVED SEQUENCE OF EVENTS IN THE P2 LOSS-OF-FLOW TEST

Event	Observed Time, sec
Start Flow Transient	0.0
Onset of Sodium Boiling	6.3
Inlet Flow Reversal	11
Cladding Failure	9.5
Onset of Cladding Motion	10.5 - 11.5
Hex-can Failure	14.0
Fuel Eruption	14.3
Reactor Scram	21
Shroud Failure and Upper Blockage Penetration	22

**PHYSICAL PECULIARITIES OF HIGH TEMPERATURE MOLTEN-SALT
REACTORS IN THE FREE CONVECTION REGIME WITH THE USE OF
GASLIFT**

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EXTENDED ABSTRACT

Continuous rise in gas- liquid organic fuel price determines the interest in the nuclear reactors which can produce high temperature heat.

High Temperature Molten-Salt Reactor (HTMSR) in the free convection regime is the type of reactor which can produce high temperature heat, using Li, Th and U fluorides at the temperature about 1300°C and special sorts of graphite as the construction moderator material.

These reactors have the following advantages:

1. HTMSR is a high temperature heat generator, which can transmit heat to the technology circuit in the narrow temperature range.
2. The HTMSR moving pressure doesn't exceed 1 atm in the convection regime and vapour pressure of the fuel salt is 0,1 atm.
3. The use of HTMSR convection regime excludes the pump equipment. This ameliorates the safety problems.

HTMSR is an uranium-thorium reactor placed in the metallic tank being cooled, which is coated inside with graphite laying. The core is formed of graphite bars, in which, while being heated, the fuel salt rises. Further, the salt gets in to the isothermal lifting section, where the gaslift can be used for the additional intensification of free convection of the fuel salt. From the lifting section the fuel salt gets in to the over-flow zone, where the gas being blown in is removed from the salt surface. After that the fuel salt gets in to the movable section, where the heat exchanger is placed. Graphite tubes of heat exchanger are longitudinally washed by the fuel salt.

The estimated heat physics parameters of the HTMSR's core for free convection regime and with the use of gas lift are indicated in Table 1.

It should be noted, that gas lift free convection intensification gives an opportunity to provide the total power compared with that achieved in forced convection regime of the MSER.

Table 1: REACTOR HEAT PHYSICS PARAMETERS

Reactor	MSBR	HTMSR	
1. Circulation	forced	free	gaslift
2. Thermal power, Mw	2250	460	2000
3. Fuel salt volume, m ³	48,7	51,5	67,9
4. Special fuel charge, kg U/Mw(th)	0,7	3,5	1,0
5. H_c/H_{ls} , m	4/0	4/6	4/6
6. T_1/T_0 , °C	566/704	1100/1300	
7. Moving pressure, atm	8,2	0,06	0,86
8. Mean flow velocity of fuel in core, m/s	2,1	0,4	1,4
9. Channel equivalent diameter in core/ in heat exchanger, cm	$\frac{1,5}{0,7}$	$\frac{5}{1,5}$	$\frac{5}{1,5}$
10. Flow rate of gas in lifting section, m ³ /s	-	-	2,35
11. Heat exchanger square, 10 ⁻³ cm ²	3,90	4,06	4,06

there H_c, H_{ls} - core and lifting section height,
 T_1, T_0 - inlet and out fuel temperature

QUANTITATIVE PREDICTION OF THERMAL DIFFUSION
IN GAS MIXTURES BY USE OF THERMODYNAMICS

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EXTENDED ABSTRACT

INTRODUCTION

Thermomigration (also termed thermotransport or thermal diffusion) is the migration of a component of a solution with respect to the other component(s) as a result of the presence of a temperature gradient. Although this phenomenon is well known for gases, liquids and solids, no method for its quantitative prediction exists in the current literature for any state of matter. In the case of gases [1] the situation is ambiguous because in principle the Chapman-Enskog theory gives a rigorous treatment of thermomigration, whereas in practice the detailed kinetic-theoretical calculations in question cannot be carried out even for a binary system at normal pressures, such as the carbon dioxide/argon mixture chosen as the example in the present paper. A thermodynamic approach, being independent of a detailed mechanism, is far simpler than a method based on specific intermolecular forces. The first clue to an appropriate thermodynamic procedure was discovered by the author in a study of thermomigration of carbon ions within a motionless framework, the crystal lattice of face-centered cubic iron. An appropriate analysis showed that the direction of migration (and its magnitude to within a factor of two) are determined by the excess partial entropy, s^{xs} , of the carbon component. The same procedure applied to the conduction electrons in a metallic crystal lattice showed that the corresponding thermomigration effect, the Seebeck coefficient (or absolute thermopower), is determined by the excess partial entropy of the conduction electrons [2].

The definition of excess entropy, s^{xs} , convenient for the present purpose divides the total entropy of mixing per molecule, s , into two portions,

$$s = s^c + s^{xs} \quad (1)$$

where s^c is the configurational entropy calculated for a (hypothetical) system of noninteracting particles and s^{xs} is the excess entropy attributable to the interactions that exist in the physical system in question. The procedure for evaluating s^{xs} , both for pure gas and for a mixture, involves the use of residual entropies [3] calculated relative to the properties of the physical gas extrapolated to zero

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pressure. The gas then obeys the perfect gas law,

$$PV=RT \quad (2)$$

although the physical gas differs from a hypothetical gas since the Joule-Thomson effect exists even at pressures approaching zero [4].

The present thermodynamic method involves several relatively distinct aspects. The starting place is the existing treatment of diffusion and of thermomigration in a binary gas mixture by momentum-transfer theory [5]. This theory gives a quantitative value, α_T^h , for the thermal diffusion factor for non-interacting (hypothetical) molecules. The super (C), meaning configurational, indicates that this portion of α_T is attributable to the properties (such as mass, velocity, etc.) that the molecules in question would have in the absence of interactions. The total quantity,

$$\alpha_T = \alpha_T^C + \alpha_T^{xs} \quad (3)$$

includes a second portion, α_T^{xs} , attributable to the interactions that produce the excess entropy.

To evaluate α_T^{xs} , the process of collision between unlike molecules 1 and 2 is treated by transition-state kinetic theory, the configuration (activated complex) at the instant of collision being the transition state. This procedure identifies $(\bar{s}_1^{xs} - \bar{s}_2^{xs})$ as the essential factor in α_T^{xs} . Quantitative values of $\bar{s}_1^{xs}$ are obtained from the virial coefficients of the gases being studied and permit a comparison of the calculated values of α_T given by Eq. (3) with the experimental values available in the literature.

Analysis of Unlike Collisions by Transition-State Theory Momentum-transfer theory shows that only collisions between unlike molecules contribute to diffusion or to thermomigration and that an analysis based on the one-dimensional case can be easily modified to include spatial aspects. Furthermore, because this theory adequately treats (hypothetical) noninteracting molecules (for which s^{xs} is zero), the present analysis focuses attention on the effect of interactions (as measured by the value of s^{xs}) on the process of collision. For this purpose the collision of the lighter molecule, M_2 , with the heavier molecule, M_1 , in the center-of-mass reference frame is treated as the bimolecular reaction [6],



leading to the formation of the transition-state species (activated complex) $S^\ddagger$ formed by M_2 and M_1 at the instant of collision. The version of transition-state theory employed here is the same as that used by Darken and Gurry [7].

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Determination of Excess Entropy and Evaluation of α_T^{xs} The excess entropy of interest here is not merely the usual excess entropy of mixing but is the total excess entropy of a mixture of gases above the entropy of the corresponding (hypothetical) non-interacting molecules. The quantities that determine α_T^{xs} are the partial excess entropies, $\bar{s}_i^{xs}$. In a binary solution the total excess entropy, s^{xs} , is the weighted sum of the partial excess entropies of the two components [8],

$$s^{xs} = X_1 \bar{s}_1^{xs} + X_2 \bar{s}_2^{xs} \quad (5)$$

where X_i is the mole fraction of component i . The values of $\bar{s}_i^{xs}$ are identical with the residual entropies, $S^*(V,T)$, of Rowlinson [9],

$$\bar{s}^{xs} = -\frac{R}{V} \left(B + T \frac{dB}{dT} \right) \quad (6)$$

where B is the second virial coefficient in the equation of state for one mole of gas.

Comparison with Experimental Data An experimental study by Cozens and Grew [10] of thermomigration in a 50 mole percent mixture of carbon dioxide and argon confirmed the earlier observation by Waldmann that the thermal diffusion factor, α_T , anomalously decreases with increasing temperature. The agreement of α_T^C with the minimum on the experimental curve is excellent. The values of α_T , although of limited accuracy, show correctly the anomalous decrease with increasing temperature.

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PROSPECTS FOR NON-ELECTRIC APPLICATION OF HIGH TEMPERATURE REACTORS

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Except for nuclear military production and some aspects of ship propulsion, all applications of large nuclear reactors to date have been for electricity generation. With the beginning of the end in sight for naturally occurring fluid fuels, it is appropriate to consider whether nuclear energy should not assume a broader role.

If we eliminate exotica, nuclear reactors primarily produce heat. For a given quantity of heat, the higher its temperature, the broader its potential. Hence, non-electric applications identify generally with high temperatures. Trade-offs between temperature and other factors can be examined later if it looks worthwhile.

Much study has already gone into this subject, and new research is not involved in this paper. Rather, we take a look at high temperature reactors, primarily pebble bed and prismatic graphite, and at processes such as the thermochemical heat pipe, coal gasification, steel making and thermochemical water splitting, and particularly at the components necessary to link the reactor to the process. This last is where the technical problems unique to nuclear process heat lie.

Since reactors with outlet temperatures of 750°C to 950°C have been built in significant sizes and operated for several years it can be said with confidence that this technology is in hand; but the coupling of the reactor to the balance-of-plant carries still formidable challenges in the upper end of the temperature window (850°C to 950°C). Work is needed in the development of materials and the fabrication of heat exchangers and process heaters. Both iron and nickel alloys which would otherwise be suitable for application at these temperatures are susceptible to carburization from the carbon impurity carried by the helium coolant. There is also a potential problem of dealing with the tritium which comes from 4 sources within the reactor; and which will contaminate the coolant and tend to diffuse through the process heater.

In the chemical processes, the problems involve the products and their yields. In the thermochemical heat pipe, there is danger of carbon deposition if the thermodynamics get slightly out of control. Once deposited, it is very hard to get the carbon taken up again, even if the thermodynamic balance is restored. In the case of coal gasification, differences between the nuclear heat process and a combustion process may result in considerably poorer yields for the nuclear case.

The higher temperature that can be utilized via a coal fired process is a big advantage unless one of the new lower temperature catalytic processes, such as that being pursued by Exxon, proves practical. To become attractive, either a cheaper catalyst than potassium carbonate or a better catalyst recovery process than exists now will be required.

We also look at the institutional problems which must be solved if fission is to contribute in the area of process heat. These are important because nuclear reactors can't compete in small sizes but become increasingly attractive with capacity because of a large economy-of-scale factor. This implies a conglomeration of users for one plant's heat output. Reactors are likely also to become more attractive with time since fuel is expected to increase in cost more rapidly for competing energy sources. Nuclear reactors will, of course, bring with them the question of fuel cycle, fuel availability and licensing and all that goes with it. These issues are probably too well known to be discussed here, but they certainly impact the institutional considerations.

Next we make some assessment of the programs currently in place around the world. The group in Jülich, FRG is clearly the global leader having developed the pebble bed reactor and having operated the AVR for three years with an outlet temperature of 950°C. The demonstration plant of the ADAM and EVA thermochemical heat pipe is rapidly approaching operability and will lead to an early complete nuclear process heat system. Japan is also moving out aggressively with a particular eye on steel making. In the U.S., General Atomic is recognized as a leader in developing both nuclear and process technology. Gas Cooled Reactor Associates is spear-heading institutional efforts, and the Department of Energy is the primary source of support in both instances.

Finally, this paper compares some of the economics of nuclear process heat to other energy sources and other technological approaches to the same end point. For instance, with improved electrolysis near at hand, it may be hard to beat the electric path to a hydrogen economy.

ABSTRACT

STATUS REPORT ON THE FUSION BREEDER*

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Early in the development of nuclear power, people realized fusion neutrons could transform fertile material into fissile material in the same way fission produced neutrons breed fissile fuel. That is, neutrons independent of their source can be used to breed. The nuclear processes are well known. What is not well known is how and when we can build a practical, operating fusion reactor. In fact, no one knows even how difficult the job will be. On the other hand everyone agrees that great progress has been made in controlled fusion experiments, leading many to predict energy breakeven will be achieved in the 1980's. It is clear fissile fuel breeding is less demanding of the fusion driver than pure fusion but by an unknown amount.

The paper will show that much of the technology for the fusion breeder is the same as for fusion power, but revenues from fuel production can be over twice that from power production so that higher capital cost of early fusion technology will still be economically acceptable. We can therefore speculate with some certainty that the fusion driver technology for a fusion breeder will be available before the same technology has progressed even further to be suitable for power application.

The technology of the blanket wherein fuel breeding takes place has been the subject of a number of studies which will be reviewed. These blanket types can be categorized by the quantity F/M , where F is the fissile atoms produced per fusion neutron and M is the blanket nuclear energy released per fusion neutron divided by 14 MeV. The quantity F/M is the fuel production per unit of blanket energy and can be expressed as a dimensionless number as defined or with the dimensions kg fissile fuel produced per year per MW of blanket power. Blankets containing high fractions of ^{238}U produce ^{239}Pu by fast fission of ^{238}U and neutron capture reactions; these blankets have relatively low values of F/M and thus produce large quantities of power. They are nonetheless much greater producers of fissile material than are fission breeders of the same power. Blankets containing ^{232}Th produce less power and hence have a higher F/M value. Fission reactions in the blanket can be suppressed by first moderating neutrons, then capturing them in ^{238}U or ^{232}Th . For these fission suppressed blankets the value of M is only

* Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under contract number W-7405-ENG-48.

slightly greater than for pure fusion, hence M is small, so the ratio F/M is very high. These fission suppressed blankets produce so much fuel (about 6 tonnes per year for a 4000 MW nuclear plant) that they are essentially fuel factories. Several values of F and M are given in the table for three different classes of blankets in which breeding takes place.

Table of Performance of Three Classes of Blankets

	Fast Fission <u>U - Pu Cycle</u>	Fast Fission <u>Th - U Cycle</u>	Fission Suppressed <u>Th - U Cycle</u>
M	11	5.2	1.5
F	k1.5	0.8	0.7
F/M	0.14	0.15	0.47

The points made by this paper will be the following:

- o explain the role of fusion breeders in the context of fission and fusion technology development
- o review the studies of the fusion breeder
- o suggest the fusion breeder be considered by the community concerned with assuring fuel supplies for the "fission enterprise"

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UP/DOWN FUSION AND FISSION

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EXTENDED ABSTRACT

Fusion reactors, unlike fission reactors, are a marvelous potential for man in his quest for ever greater amounts of power. We think we know how fusion reactions work, but we cannot start building such plants. The fusioning of atoms of low mass into atoms of heavier mass, with a release of excess heat, can take place only when the temperature of the atoms is many millions of degrees of temperature. Such conditions may exist within stars, and the commonest mechanism is the "burning off" of hydrogen accompanied by a slow build-up of helium. The inner workings of a fusion reactor must consist of a highly chaotic swarm of charged particles. Containment will be accomplished, if at all, by a magnetic bottle type, force field, which is created inside a vacuum chamber. Excess heat will reach the vacuum chamber walls as radiant heat and a bombardment of neutral particles not stopped by the magnetic forces.

Since vacuum chamber walls will be metal, they will act as a window to fast neutrons which will be thermalized and captured by lighter materials external to the chamber walls, which will in turn create showers of hard gammas. The reactor rooms of fusion power plants will be radioactively "hot" during operation, and must be shielded, using thick concrete walls much as in fission plants. Here, any similarity ceases. Irradiated material within fusion reactor rooms will become radioactive in time, but these materials will be non-toxic, of lighter mass, far fewer in number and of shorter half-life. In the event of accident there will be no release of radioactive material into the ambient environment, as can happen in a fission reactor plant. Man-made, steady state fusion "fires" should be very easy to turn off in view of the egregious technical difficulties involved with starting and maintaining them. Unlike most power plant systems, it is not possible to start on a small scale. If a system is devised that is practical, it will be big and very expensive. The tremendous costs can be justified if the station capacities in KW are very large. Unlimited power would be available through fusion reactor plants and fuel is totally plentiful.

We should intensify our R&D efforts to solve the extremely vexing technical problems. If we succeed, we will have no energy shortage and can envision practical space travel, not only to other solar planets, but to other stars. That we may not succeed should not deter us; at least we would have tried. Inability to predict when we will succeed, if ever, makes it vital that we also develop alternate energy sources that will allow us to exist here on earth as we want to, for as long as we can. I recommend a THUMBS UP VOTE for fusion power plant development.

Fission reactors may be likened to the other side of the nuclear coin. The technology exists. There are many types, ranging from small research

reactors, plutonium production reactors, fission reactor power plants, to A-Bombs. Fission reactors can have fast neutron fluxes moderated or thermalized using heavy water, beryllium, carbon, light water, or not at all. Reactor thermal heat can be removed using recirculated coolants such as liquid metal, helium gas, pressurized light water, boiling light water and pressurized heavy water if reactors are large. Very small reactors can be cooled by immersion in swimming pools, mechanical ventilation or by detonation. Fuel can be plutonium, enriched uranium or natural uranium in the form U_3O_8 in zirconium cans.

America and other nations have spent enormous sums on various atomic programs relating to the use of fissionable materials for peaceful purposes as well as war. We have produced reliable A-bombs and can use them to trigger H-bombs. The detonation of an A-bomb lasts a few thousandths of a second after a critical mass is initiated. The yield of fissions relative to maximum possible fissions is low. The weight involved is a few tens of Kg. Nonetheless, after several years, growing traces of radioactive fall-out were found in forage. Today, prudent nuclear nations detonate test devices underground. Mobile fission reactor power plants in the order of 10,000 KW were developed to drive nuclear missile-laden submarines. Once a power reactor is turned on, it is, in about 10 minutes, as radioactive internally as it will every be, and final cooling of spent fuel will take in the order of a million years. Nuclear submarine plants contain a few hundred kilograms located behind packed lead shielding canned in a wetted steel hull located below the waterline. A core meltdown in port would not threaten landlubbers. Submarines lost at sea end up under great depths of water and radioactive contamination is remote. During the same period we cancelled a program to power planes using reactors as unnecessary, very expensive and downright dangerous.

Numerous fission reactor power plants have been built and put into operation in the absence of a decision as to what to do with nuclear wastes. Right after World War II, many of us wanted to see peaceful uses of atomic power come to the fore. Almost unwittingly we "crossed the Rubicon" as practical systems were developed. Of most interest are the two light water moderated "boiling water" and "pressurized water" systems which require 3% enriched uranium fuel, and the CANDU reactor which is moderated and cooled using heavy water. Although first reactor plants were small, today we have plants of three units of 700 MW capacity or two units of 1100 MW capacity. Single unit plant sites are normally sized for added units and the possibility of enclaves of units has been publicized. Large fission reactors involve a few hundred thousand kilograms of fission products (and unspent fuel) at a large power plant site. Spent fuel elements must be removed and replaced with fresh fuel elements if the plants are to continue to produce power. Typically, light water moderated plants must be shut down for a year while this change is effected. In sharp contrast, the CANDU reactors can have fuel elements of natural uranium oxide replaced while in operation. Instead of building extensive separations and enrichment facilities, or "buying American", they opted for an extensive plant on Hudson Bay to separate heavy water from seawater.

No safe plans have been developed to dispose of nuclear ashes. This is because there is no safe way. The media have referred to many plans. A recent suggestion was to rocket wastes to "another galaxy." The media have also reported escape of small quantities of plutonium from containment at Hanford, Oak Ridge and in Canada in recent years. We cannot bury the stuff because a future Mount St. Helens could spread it all over. We cannot blast it into outer space because rockets can blow up on the pad, or malfunction with uncontrolled reentry and burn up high in the stratosphere with a resulting fine distribution. We cannot park the stuff in Antarctica which has not always been arctic and has coal seams and residual insect life. In far less than a million years the fission product containers could be deep in salt water under corrosive attack. Pelletizing fission products in glass blocks sounds great until one sees sizable pieces of glass being pounded into sand on any beach. The safest place to leave spent fuel elements is in the safety containers wherein they became radioactive.

A recent report [1], written by two Englishmen, on what happened at Three Mile Island, was very well done by authors of impeccable background and contains 11 diagrams and graphs. A number of points of interest were described. The core of the stricken reactor was bared to steam as opposed to water three times in the early going. One instance was very brief during the other two, meltdown of fuel elements took place. Maximum fuel element temperature reached or exceeded the melting point of zirconium fuel cans, which is 2,128°K or 3,830°R. The off-site irradiation was extremely low. A series of radioactivity readings, taken at 20 minute intervals, starting four hours after the accident, were 200R/hr/ 600R/hr, 1,000R/hr and 6,000R/hr. Readings were taken behind 4" of lead some 20m above the reactor. At 600R/hr, 90% of people exposed will die. Finally, borated water has been used to cool the burned-out core which now has a friction of 200-400 times normal value, and will require equivalent cooling for hundreds of thousands of years. Boron ten soaks up thermalized neutrons and prevents resumption of core meltdown (Boron ten is 19% of all boron atoms).

Let us consider current economics of fission power plants. A recent report [2] on three Commonwealth Edison fission power plants, of 2,156 MW, 2,240 MW and 2,240 MW capacity, stated delays of eight months, 12 months and 24 months, for completion in 1982, 1984 and 1986, at new estimated construction costs of 2.0, 2.7 and 3.1 billion USD (or 928, 1,205 and 1,384 \$/KW). A very late report on five Washington Public Power Supply Systems (WPPSS) states construction costs rising from 4 billion USD in the early 1970s to 11.8 billion in 1979 to 15.9 billion in 1980. The five WPPSS plants are four to five years behind schedule [3]. To this must be added the cost of fuel elements starting with \$50/# for U₃O₈ [4], cost of fuel enrichment and cladding, the cost of pumping borated water for an eon if something goes wrong, up to 500 million USD if a core meltdown ruptures containment, and the future cost of "safe disposal" of nuclear ashes for a million years per spent reactor core if nothing goes wrong. These plants are also labor intensive due to need for operational health physics and frequent shutdowns.

These plants cannot be justified because they are only 25% efficient, are

very expensive, nuclear fuel is rarer than coal, oil and gas, and they operate about 67% of the time as opposed to 88% on-line record of fossil-fueled plants. Breeder reactors are said to create more fuel than consumed to the extent that fuels will last longer by a factor of 60. Breeder reactors make more sense, but not enough sense. While nuclear fuel could be regenerated again and again, cost per plant is much greater, on-line time will be no better and chances of accidental escape or theft of nuclear wastes are greatly increased. Many of the above points were contained in an earlier publication /5/. It is concluded that fission reactor power plants of large size are obsolete and should be SHUT DOWN SYSTEMATICALLY, as other, safer, and less expensive methods of power generation come into use. The great hope of nuclear power generation for the benefit of man lies with fusion reactor plants.

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PROSPECTS FOR PRACTICAL FUSION POWER

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EXTENDED ABSTRACT

INTRODUCTION

The prospects for practical fusion power received a substantial shot in the arm recently when President Carter signed into law the Magnetic Fusion Engineering Act of 1980. This new law directs the Secretary of Energy to "initiate at the earliest practical time each activity which he deems necessary to achieve the national goal for operation of a commercial demonstration plant at the turn of the twenty-first century".

The new law is in consonance with the conclusions of two review panels which reviewed the status of magnetic fusion energy research during 1980. A Fusion Advisory Panel to Congressman Mike McCormack, chaired by Dr. Robert L. Hirsch, concluded that "fusion can be made commercial before 2000 if a national commitment is made soon". And, the Department of Energy's Energy Research Advisory Board (ERAB), chaired by Dr. Solomon J. Buchsbaum, concluded that "recent progress in plasma confinement has been impressive" and that "as a result of this progress, the U.S. is now ready to embark on the next step toward the goal of achieving economic fusion power: the exploration of the engineering feasibility of fusion".

The basis for optimism that fusion will become a practical energy source around the turn of the century is three-fold: (1) dramatic scientific progress has occurred on a broad front during the past few years; (2) key fusion technologies have been developed for several large fusion facilities now under construction; and (3) a growing cadre of engineers have emerged who have been identifying the engineering development tasks required for practical systems.

SCIENTIFIC PROGRESS

Leading the way, scientifically, has been the tokamak concept. Within the past 5 years tokamak experiments have pushed the individual parameter achievements, used to estimate the practicality of fusion, past those values required for the generation of net fusion energy. The increased understanding gained in these experiments enhances our confidence that a commercial fusion reactor can eventually be constructed. Progress has also occurred in other concepts, such as magnetic mirrors and bumpy torus and in inertial fusion.

TECHNOLOGY DEVELOPMENT

Major strides have been made in developing components for higher power fusion systems. These include higher power, longer pulse neutral beams, gyrotrons, lasers and pulsed power systems. An array of 6 large superconducting magnets is being installed into a test assembly at Oak Ridge National Laboratory; a Tritium Systems Test Assembly is under construction at the Los Alamos Scientific Laboratory and a Materials Irradiation Test Facility is under construction at the Hanford Engineering Development Laboratory.

ENGINEERING DESIGN

An increasing number of studies are focussed on identifying the engineering technology tasks requiring solution. One notable effort underway in this area is the conceptual design at the Argonne National Laboratory of a tokamak reactor called "STARFIRE". Studies have indicated that the cost of electricity from fusion in the twenty-first century should be competitive with electricity produced from other sources.

PROGRESS IN FUSION ENERGY - A LEGISLATIVE PERSPECTIVE*

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INTRODUCTION

It is the purpose of this paper to present some of the accomplishments which have taken place in the Department of Energy's magnetic fusion energy program over the past few years and to show how these accomplishments, coupled with a Congressional recognition of the need for further work on long range energy research programs, has led to the introduction of important fusion legislation. This legislation will be traced through both Houses of Congress and details of the final legislation and its possible implications will be discussed. The bill, as agreed to by the House and Senate, should be signed into law by the time this International Conference meets (Dec. 15-17, 1980).

Perspective The goal of commercial fusion power has been pursued since the early 1950's. The first 20 years were characterized by high expectations, low budgets and little obvious progress toward practical fusion power. In recent years, however, increased funding and attention have produced significant experimental results which indicate practical fusion power may be within reach. The next major scientific goal of the fusion program is to meet the requirements necessary for energy "breakeven" (producing as much power from fusion as is consumed in maintaining the fusion reaction conditions).

As proof of scientific feasibility draws closer, attention needs to focus on a demonstration of engineering feasibility which is the next step in the development of practical fusion power. This will be accomplished in a proposed Fusion Engineering Device (FED) or Fusion Engineering Test Facility (FETF) -- a test fusion reactor that will produce at least as much energy as is required to operate an entire power plant continuously. Although there are a number of major technical problems which must be addressed in the engineering feasibility stage, the fusion community is confident that none are insurmountable. The current Federal fusion development plan has a target date of the late 1990's for an operational FED/FETF. In view of the recent experimental results, the Congress appears convinced that with an aggressive Federal program a FED can be operational by 1990. If progress over the next decade is comparable to the successes produced during the last few years, then it would seem feasible to follow this FED with a prototype commercial demonstration reactor to operate in the 1995 to 2000 time frame. The FED/FETF is, however, the near term key to a determination of whether or not fusion power can be a practical reality.

In terms of budgetary perspective, the annual magnetic fusion research budgets during the 1960's and early 70's were on the order of \$30 million. Real program growth occurred with an increase from \$43 million in 1973 to \$316 million in 1977. This signaled the shift from small research devices to major scaling experiments. The budgets since 1977, while increasing slightly up to 1980, have, in fact, decreased by over 16% when account is taken for inflation. The FY 1981 fusion budget is presently \$394.1 million (solar + geothermal approximately \$725 million; fission over \$800 million) and supports programs at 10 national scientific and engineering laboratories, 15 industries (mostly major subcontractors to laboratories), and 30 universities.

Scientific Status Among the many types of fusion devices which use magnetic fields to confine hot ($100,000,000^{\circ}\text{K}$), fully ionized plasma, the approach which has demonstrated the most advanced scientific parameters to date is the tokamak (a Russian invention). All of the temperature, density, and confinement time requirements for achieving an energy "breakeven" condition have been achieved separately in laboratory experiments using this tokamak concept. Most of these results have occurred over the past two to three years. With these results, fusion researchers are now predicting (e.g. Physics Today, May 1979, p. 31) that breakeven conditions can soon be achieved simultaneously in one or more of the major devices now under construction (e.g., the Tokamak Fusion Test Reactor at the Princeton Plasma Physics Laboratory, scheduled to operate by early 1982).

In addition, significant progress has been achieved in other types of confinement devices, e.g., the Tandem Mirror Experiment at Lawrence Livermore Laboratory and the ELMO Bumpy Torus device at the Oak Ridge National Laboratory. In response to these successes the MFTF-B tandem mirror (TEC \$225 million) and the EBT-P (TEC \$70-\$100 million) projects have recently been approved by Congress and the Administration.

Need for Legislative Action Since the fusion budgets have not grown at a rate to keep pace with the scientific achievements in the program, both Houses of Congress sought to identify the critical items influencing program pace. It was determined through hearings, use of advisory panels, and review of the studies produced by the international scientific community, that the magnetic fusion program in the U. S. was not technology-limited -- it was clearly funding-limited. All studies, to date, have shown that the next logical step in the progression to commercial fusion power was the construction of a Fusion Engineering Device (called by the Department of Energy a Fusion Engineering Test Facility). Consequently, any delay in proceeding with this device will result in a delay in moving to commercial feasibility -- the final stage of fusion power development.

To avoid unnecessary delays and increased costs, the Congress has recommended (through legislation) that the Nation proceed now with the development of the FED. This will require a strong and decisive Federal commitment to fusion and its technological development. With development costs measured in the billions of dollars and no immediate return on investment, the private sector cannot be expected to make significant contributions to the fusion effort at this time. The Federal Government, therefore, must continue to support the majority of the fusion research and development effort, an investment which seems worth the expense in view of the ultimate potential of fusion power.

Legislative History In response to the need for further legislative action, on January 28, 1980, Congressman McCormack introduced the Fusion Energy Research, Development and Demonstration Act of 1980, H.R. 6308. This bill constitutes the first legislation ever introduced to address fusion energy technology. The Subcommittee on Energy Research and Production of the House Committee on Science and Technology held hearings on fusion energy and this legislation on December 11, 1979, and February 26, March 3 and March 6, 1980. The Committee ordered the bill reported on June 4, 1980, having obtained the cosponsorship of 160 Members of the House of Representatives. The legislation was considered by the House under a Suspension of the Rules on August 25 and was passed by a vote of 365-7.

On July 2, 1980, S. 2926 was introduced by Senator Tsongas with Senators Church, Domenici, Baker, Bradley, Williams, and Sasser as original cosponsors. The bill was referred to the Committee on Energy and Natural Resources. The Subcommittee on Energy Research and Development held hearings on July 28 and August 5, 1980. On September 10, the Committee ordered the bill reported after adopting 5 amendments and authorizing technical and clarifying amendments to be made by the staff. The Committee noted at the time of reporting the bill the addition of 16 more cosponsors: Senators Huddleston, Laxalt, Matsunaga, Bumpers, Hayakawa, Stevenson, Moynihan, Goldwater, Dole, Cranston, Hollings, Danforth, Javits, Garn, McClure and Pell.

The wording of the Senate bill as amended was introduced as an alternate to the already passed House bill on the Senate floor, and passed on September 23, 1980. The House concurred with this bill and sent it to the President for enactment into law. By the time of this International Conference on Alternate Energy Sources, the U. S. may have a new national policy to guide the development of fusion energy.

*The opinions expressed in this paper are those of the author and do not necessarily represent the opinions or policies of the Committee on Science and Technology, Congress of the United States.

THE DECISION TO PURSUE FUSION ENERGY

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EXTENDED ABSTRACT

INTRODUCTION

Fusion is a virtually limitless potential source of energy. Successfully developed, fusion could be clean, safe and reliable. Using advanced reactions, fusion fuels are readily available, thus making ample energy available to all peoples. By almost any measure, the development of fusion energy technology would be a milestone in the evolution of man.

Unfortunately, fusion energy is not the panacea that it would at first appear to be. The principal problem is that fusion technologies are not trivial: they have been under development for 25 years already and are likely to require another 25 years or more of research before being ready for commercial use. Even after successful technology development, it will be an additional 30 to 50 years before fusion energy constitutes a major fraction of man's total energy production. Thus, few people alive today will derive a significant portion of their total energy consumption from fusion. Add to this argument the fact that known fossil fuels will last for at least several more generations and the justification for pursuing a vigorous program of fusion research does not appear evident.

In choosing to fund fusion research, the principal issues are: What is in it for me and what is in it for others, including future generations (in that order of importance)? In terms of broad choices, man can devote his labors to the production of consumable goods, to the production of capital goods (principally for the purpose of increasing future production of consumable goods), or to research that can improve the quality of life. With respect to energy, the main effect of research is to enable the production of more goods with less labor. Implicit in the choice to pursue fusion energy, therefore, is the notion that something is foregone today to provide more for the future. Is this sacrifice worthwhile?

A FRAMEWORK FOR EVALUATION

The evaluation of any long-range effort involves the tradeoff between consumption today and consumption in the future. If the value of consumption can be measured in dollars, this tradeoff can be quantified using the process of discounting. Discounting recognizes that a dollar received today is worth less than a dollar received in the future (even correcting for inflation) and thus reduces, or discounts, future revenue streams according to when they occur. The discount factor is generally taken to be $e^{-\rho t}$ where ρ is referred to as the discount rate and t is the time between the reference date used for the analysis and the time of a particular cost or benefit.

Several years ago, the Office of Management and Budget (OMB) recommended the use of a ten percent per year discount rate for the evaluation of Federally-sponsored programs, including research. Because of the power of the exponential, however, at a ten percent discount rate, benefits received 50 or more years in the future are perceived as having essentially no "present" value. This leads to the intuitively unappealing conclusion that fusion research provides practically no value to society and certainly no value to people that are presently paying taxes.

Recent examinations, however, indicate that the OMB-recommended discount rate is inappropriate and that a 3-5 percent per year rate would be more in line with present performance of the economy. At the lower discount rate, the perceived benefit of fusion energy can be quite substantial.

A second major issue relating to research on long-range energy alternatives is that, by its very nature, such research is fraught with uncertainty. There are uncertainties on the schedule by which the effort is conducted, the cost of the effort, and most fundamentally, its outcome--success or failure. A common evaluation approach has been to estimate the benefits of a research program, downweight these benefits by an estimate of the probability of program success and compare this result to the estimated program cost. Unfortunately, any particular long-range alternative generally has a rather low probability of success and, thus, the result of this procedure is that the estimated program benefits are downweighted substantially. It is interesting to note that while this procedure, widely referred to as benefit-cost analysis, downweights benefits by probability of success, no such weighting is applied to the research costs. It is assumed that all research funds are committed at the outset of the program with no options open but to wait until the funds are spent and see how the program turns out. This is not a reasonable model of a long-range research program.

In general, long-range research programs consist of a sequence of phases, each with specific activities, specific goals and associated costs. Each research phase is separated from the previous phases by a decision, the decision to pursue it. Thus, the decision to pursue a particular research phase is only a decision to commit to incurrence of the costs associated with that phase, not the costs of an entire program. As the decision is made to pursue each successive phase, uncertainty in the outcome of previous phases has been resolved and the probability of success is commensurately higher. In essence, research is a process of sequential reduction of uncertainty--it is the purchase of information--and it must be evaluated that way.

The third major issue is that while long-range alternatives offer to become the major sources of energy at some time in the future, 50 or 100 years from now, they do not provide energy today. Today's energy derives from a pool of resources--oil, gas, coal, uranium--that is widely recognized as being "exhaustible," that is, for which production costs will certainly increase substantially in the not-too-distant future. In general, the holders of a limited resource, be they monopolists or cartels such as OPEC or society at large, would choose to allocate the resource across time--intertemporally--in a manner which provides them with the greatest possible derived benefit from the resource. But since the

future value of a resource such as oil depends on the future existence or nonexistence of alternative resources, and since the future existence of alternatives depends on research today, the current optimum consumption rates for the presently available resources depend on the nature and extent of current research activities.

To state the issue another way, suppose there would never be a substitute for crude oil. Then the value of crude oil, reflected by its price today, would be very high because of its future uses. On the other hand, if one could reasonably expect that in, say, 30 years substitutes for crude oil would be available, this expectation would reduce the future value of oil and, hence, also today's price. This effect applies even if the expected cost of the substitute is substantially higher than the current price of crude oil since, because oil is a limited resource, its production cost is sure, at some point, to rise above the cost of the substitute. It follows that research which provides a credible expectation of future energy alternatives yields a significant and important benefit to society today.

CONCLUSIONS

It is shown that, while it is easy to arrive at the conclusion that fusion research is not an economic undertaking, thorough and proper analysis of the issue can lead to quite a different result. First, one must deal correctly with the discount rate, properly separating the effects of inflation from those effects that are real. Correct evaluation and use of the discount rate leads to a greater recognition of future welfare compared to current welfare. Secondly, one must delve into the economics of nonrenewable energy resources. Here one discovers that today's prices of nonrenewable fuels are linked to ongoing energy research programs through the expectation of a shift in future demand for the resource brought about by the research and it becomes clear that benefits of long-range energy research can be enjoyed today by the sponsors of that research. Finally, long-range energy research must be viewed as a process of buying information, not as a process of buying a product, and evaluated accordingly.

A REVIEW OF THE CONCEPTUAL
FUSION REACTOR BLANKET DESIGNS

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EXTENDED ABSTRACT

As advances in plasma physics and impressive gains in fusion reactor technology brings us closer to commercialization of fusion power, we felt that a review of the major fusion reactor blanket and shield designs was necessary to insure that essential or desirable characteristics had not been overlooked. This review of past progress would point the way for the future direction of research and development necessary in this area to achieve the goal of commercial fusion power.

Thermonuclear reactions proceed through microscopic interactions. For fusion to occur, two light nuclei must be brought into close proximity where they fuse, forming a nucleus with increased binding energy, thus releasing energy. The blanket surrounding the fusion reaction chamber provides the means in which the fusion energy is converted into useful heat energy in a working fluid. In addition the blanket serves many other functions such as providing a vacuum tight enclosure for the plasma and means for conduction the working fluid away to an electrical generation system. The blanket and its associated shield must also protect the magnets from excessive radiation and heat. An example of a conceptual blanket design is that for WITAMIR-I [1]. A cross-sectional view of this reactor is shown in Figure 1.

A literature survey noted that a serious effort began in the early fifties [2] to achieve controlled thermonuclear power. In the late fifties [3,4] and through the sixties [5,6,7] some effort was made to conceptualize the fusion reactor blanket and shield, define its functions, and specify the requirements necessary for their construction. It has been only in the last ten years, however, that complete conceptual designs of fusion reactors and associated blankets and shields have been made.

In our paper, we review the major conceptual reactor blanket and shield designs that are a result of studies at the University of Wisconsin, Los Alamos Scientific Laboratories, and other universities and research institutes. By a careful review and comparison of the blanket designs,

we are able to clarify advantageous trends. The WITAMIR-I blanket, for example, as noted in Table 1, has a high energy multiplication which is advantageous from an economic point of view. In addition we are able to delineate those areas where more research is needed as for example in the design of the shielding for blanket penetrations.

We conclude by noting that we are rapidly approaching the point where the conceptual will become reality -- having merged with the experimental into the first demonstration power reactor. Now is the time to accelerate the research to eliminate any deficiencies in design in order to insure a successful demonstration reactor.

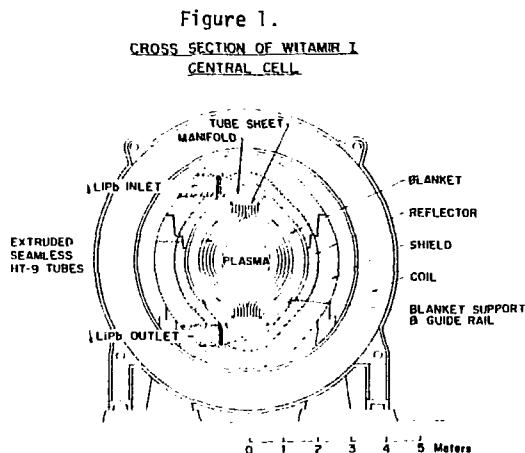


Table 1. Energy
Multiplication for
Various Conceptual
Designs

	Energy Multiplication
UWMAK-I [8]	1.17
UWMAK-II [9]	1.28
UWMAK-III [10]	1.29
NUWMAK [11]	1.22
WITAMIR-I [1]	1.37
Energy multiplication is defined as the energy deposited in the blanket per fusion divided by 14 MeV. It does not include the alpha energy.	

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FUNDAMENTAL UNDERSTANDING OF MATTER
AN ENGINEERING VIEWPOINT

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ABSTRACT

Fundamental understanding of matter is a continuous process that should produce physical data for use by engineers and scientists in their work. Lack of fundamental property data in any engineering endeavor cannot be mitigated by any amount of theoretical work that is not confirmed by physical experiments.

An engineering viewpoint will be presented to justify the need for understanding of matter. Examples will be given in the energy engineering field to outline the importance of our further understanding of material properties. Cases will be cited to show the effects of various data bases on analytical results in heat, mass and momentum transfer. The status of fundamental data sources will be discussed in terms of data centers, new areas of engineering, and the progress in measurement techniques. Conclusions and recommendations will be outlined to improve the current situation faced by engineers in carrying out their work.

APPLICATIONS OF FUSION
THERMAL ENERGY TO INDUSTRIAL PROCESSES

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EXTENDED ABSTRACT

INTRODUCTION

Fusion offers the potential of supplying high temperature thermal energy which is suitable for power and process heat generation through the consumption of an inexhaustible fuel (deuterium) and is therefore an important potential energy source.

This paper discusses the potential of utilizing thermal energy from fusion as process heat in iron-steel production, petrochemicals, cement and production of acetylene from coal via the calcium carbide method. These industries were selected because their thermal energy requirements are huge and they require the heat at high temperatures.

TRANSPORT OF FUSION THERMAL ENERGY TO INDUSTRIAL PROCESSES

Delivering the fusion heat to industrial processes involves removing the heat from the fusion blanket; transporting it to the industrial site; and utilizing it by the process. Removing the heat from the fusion blanket is essential not only for using the heat but also for proper and safe operation of the reactor. It is a question of reactor design which is beyond the scope of this paper. Transporting the fusion energy to the industrial site can be done in the form of synthetic fuels produced using the fusion heat, by low and high temperature chemical heat pipes or in the form of sensible and latent heat transfer medium. The transport method for a given application depends on the process temperature, transport distance and cost. Once the thermal energy is available at the industrial site, it is delivered to the process either by direct firing of the energy carrier if it is a synthetic fuel or by generating steam to be used in the process. Using the synthetic fuel as a chemical feed stock is also feasible.

APPLICATION OF THE FUSION HEAT IN THE IRON-STEEL INDUSTRY

Iron and steel production is an energy-intensive industry. In an integrated steel mill, primary fuel consumption for heat production per ton of raw steel produced is estimated at 18.7×10^9 Btu. Most of that heat is used for preheating the blast furnace air to above 1400°F , and for melting the steel

at 2700°F. Process steam is also required at the rate of about 1.7×10^6 Btu of fuel per ton of steel produced. This industry also consumes large amounts of hydrogen and oxygen, specially the newer plants which employ a basic oxygen furnace (BOF). Utilizing the fusion heat in a high temperature water electrolysis cycle to produce hydrogen and oxygen and transporting the hydrogen and oxygen in pipelines to the iron-steel plant site appears to be a very attractive alternative. The electrolysis plant can be located near the fusion reactor. The hydrogen can be used both as a fuel and as a reducing feed stock. The oxygen can be used as an oxidizing agent. The cost of hydrogen and oxygen plants constitute a substantial portion of the total cost of an iron steel plant. Therefore providing those two feed stocks from a central electrolysis plant can reduce the capital cost of these plants considerably. Further because coal will no longer be used air quality near these plants will improve.

APPLICATION OF THE FUSION HEAT IN THE PETROCHEMICAL INDUSTRY

The energy required in a petroleum refinery is mostly in the form of direct heat, electric power, and steam. The energy consumed for processing a barrel of oil ranges from 0.5 to 1.0×10^6 Btu. The largest portion of the heat required is between 400 and 1200°F. The petrochemicals industry also consumes large amounts of hydrogen which is produced on site by reforming natural gas and naphtha.

Because most of the energy required by this industry is in the range of 400°F to 1200°F, it can be supplied from the fusion blanket. High-temperature chemical heat pipes such as the methane steam reforming/formation system and the sulfur trioxide formation/decomposition system can be used. Economic analysis of such a heat delivery process will have to take into consideration the fact that some of the heat is conventionally produced from burning by-products. Availability of high-purity hydrogen from a fusion heat-operated electrolysis plant will conserve feedstock and energy used to produce it by reforming the feedstock. Availability of oxygen will also reduce the energy and cost associated with an on-site oxygen plant.

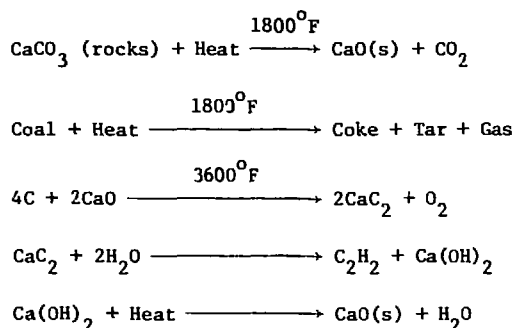
APPLICATION OF THE FUSION HEAT IN THE CEMENT INDUSTRY

The energy consumed per ton of cement produced is about 7.5×10^6 Btu. Essentially 95% of the heat is consumed in the kiln which is maintained at 2700°F at its lower end. Direct use of fusion heat in the cement industry is not practical due to the very high temperature requirement relative to the temperature of the heat source. Therefore, the cement industry can benefit from fusion thermal energy only if that energy is used to produce synthetic fuels such as hydrogen or coal derived medium and high Btu gas which have high flame temperature when burned.

APPLICATION OF THE FUSION HEAT IN THE PRODUCTION OF ACETYLENE

Acetylene is widely used as a feedstock for the synthesis of many chemicals. It is also an excellent fuel for high temperature processes because of its

high temperature flame. Acetylene can be synthesized by reacting water with calcium carbide. However, the production of calcium carbide from reacting calcium oxide with coke takes place at temperatures of about 3600°F. Such a temperature is achievable by electric resistance furnaces only, which increases the cost of acetylene appreciably. The steps involved in the process are summarized by the following reactions:



As can be seen, this process requires higher temperatures than what can be expected from the fusion blanket, therefore for the formation of calcium carbide, consideration should be given to direct contact of the reactants with the energized neutrons.

CONCLUSIONS

The conclusions of the study are--

- The production of synthetic fuels using fusion heat is a good way to store and transport fusion heat.
- The petrochemical and steel industries of the future appear to be the two most promising potential applications for the heat available from fusion reactors. In addition to being able to utilize large amounts of the available heat, they also need hydrogen and oxygen which can, be produced efficiently using fusion heat.

HYFIRE: A COMMERCIAL FUSION/SYNFUEL REACTOR*†

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EXTENDED ABSTRACT

Brookhaven National Laboratory (BNL) is carrying out a comprehensive conceptual design study called HYFIRE of a commercial fusion Tokamak reactor, high-temperature electrolysis system. The purpose of the study is to provide a mechanism to further assess the commercial potential of fusion via a Tokamak reactor for the production of synthetic fuel. The HYFIRE design is based on the Tokamak power reactor, STARFIRE [1], the primary difference residing in the type of blanket between the two reactors. The study is placing particular emphasis on the adaptability of a Tokamak power reactor to a synfuel application.

The key technical objective of the STARFIRE study has been to develop an attractive embodiment of the Tokamak as a commercial power reactor consistent with credible engineering solutions to design problems. This same philosophy is carried over to the HYFIRE study with an eye towards assessing what major changes are required for the synfuel reactor. HYFIRE is based on the deuterium/tritium/lithium fuel cycle.

The primary criteria for commercial attractiveness in HYFIRE are economic, safety, and environmental impact where economics must include the economics of producing hydrogen and safety and environmental impact include the production of hydrogen and oxygen.

The electrochemical decomposition or electrolysis of water into hydrogen and oxygen is an endothermic reaction requiring both heat and electricity. Since the heat input component for water decomposition is used directly at essentially 100% efficiency, there is a definite advantage to make the ratio of the direct heat input to the electrical energy input as large as possible. At a temperature T , the input thermal energy equals $T\Delta S$, where ΔS is the entropy change for the reaction. The electrical energy input equals the Gibb's free energy change for the reaction, and the sum of these energy changes equals the reaction enthalpy.

*Work performed under the auspices of the U.S. Department of Energy, Washington, DC.

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As temperature increases, the reaction enthalpy remains virtually constant. The Gibb's free energy or electrical energy input, however, decreases with increasing temperature and the thermal energy input, $T\Delta S$, increases. The ratio of thermal energy ($T\Delta S$) to electrical energy increases with electrolysis temperature; this results in higher process efficiency so that more hydrogen production can be generated for a given fusion energy input. For HYFIRE, the design temperature of interest is 1400°C. The heat input, $T\Delta S$, absorbed by the HTE cells during electrolysis is supplied from the sensible heat content of the process steam.

The HYFIRE blanket must perform three functions: a) provide high-temperature ($\sim 1400^\circ\text{C}$) process steam at moderate pressures (in the range of 10 to 30 atm) to the high-temperature electrolysis (HTE) units; b) provide high-temperature (~ 700 to 800°C) heat to a thermal power cycle for generation of electricity to the HTE units; and c) breed enough tritium to sustain the D-T fuel cycle. The dual requirements, generation of high-temperature process steam for the HTE's and high-temperature heat for the thermal power cycle, differentiates the HYFIRE and STARFIRE blanket systems.

The two-temperature zone blanket approach [2] is mandatory for the process steam portion of the energy supply. The modules will have relatively cool shells ($\sim 300^\circ\text{C}$) with thermal insulation between them and the high-temperature ($\sim 1400^\circ\text{C}$) interior. The two-temperature design concept is also carried over for the power cycle modules.

Steam is directly heated in the hot interior of the HTE process heat modules and then passes into the HTE electrolyzer. The steam is cooled, ~ 100 to 200°C , as it passes through the electrolyzer by the endothermic electrolysis process. In order to keep the electrolyzer temperature at a high average value, it is necessary to electrolyze only a small fraction ($\sim 10\%$) of the steam during its passage and return the steam- H_2 mixture for reheat to another section of the blanket. The optimum number of series of reheats and electrolyzers depends on various parameters. For reasons of ducting and connections to the 24-blanket sectors of HYFIRE, the number of electrolyzers are fixed at 12, one for each two blanket sectors and process parameters are adjusted to reflect the fixed numbers.

Other types of HTE process arrangements are possible to investigate activation of H_2 extraction. For example, one could make the HTE electrolyzer slightly longer (e.g., about 10%) with a separate shell side zone to transfer heat from the steam blanket coolant to the steam/ H_2 mixture flowing inside the electrolyzer so that H_2 does not come in contact with the steam from the blanket. Rather than increasing the H_2 content in the electrolyzers, the 10% H_2 can be extracted in a recuperator/condenser arrangement, thereby reducing the electrical energy requirement to produce hydrogen.

In addition to thermal energy for the decomposition of steam into its constituents, H_2 and O_2 , electrical input is required. Power cycle efficiencies of $\sim 40\%$ require He cooling for steam superheat. Fourteen hundred degree

steam coupled with 40% power cycle efficiency results in a process efficiency (conversion of fusion energy to hydrogen chemical energy) of $\sim 50\%$.

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SESSION 40

OCEAN THERMAL ENERGY I

THE OTEC ALTERNATIVE FOR PUERTO RICO VS
COAL - OIL - NUCLEAR (PHASE II)

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EXTENDED ABSTRACT

ABSTRACT

A previous study, presented at the 7th OTEC Conference-June 1980-Washington DC, evaluated the effect of a group of the commercially available energy alternatives, namely oil, Coal, and Nuclear, against the OTEC alternative for the period 1989-80 to 2009-10 in the Puerto Rico Electric Power Authority (PREPA) generating system.

This study consists of a similar long range generation expansion plan to evaluate the effect of one commercially available unit against one 450 MW OTEC unit in a previously selected coal generation expansion pattern for the PREPA system.

INTRODUCTION

Using the most recently developed maximum demand and generation forecast for the PREPA system (March 1980) one generation expansion pattern was developed using 300 MW Coal units and 370 MW Combined Cycle units as the alternative to fulfill the required base and peaking unit additions for the period 1987-88 to 2009-10. One 300 MW Coal unit is already committed for the year 1985-86 with another such unit for 1986-87.

Using this Base Pattern, three additional patterns were developed by changing the first 300 MW Coal unit in the period 1987-88 to 2009-10 by one 300 MW Oil unit (Oil Pattern), one 600 MW Nuclear unit (Nuclear Pattern) or one 450 MW OTEC unit (OTEC Pattern).

Each pattern is evaluated economically for system production cost, investment cost, outage cost and total cost. These costs are presented as leveled costs for the period from fiscal year 1980-81 to 2009-10.

METHODOLOGY

The main objective of generation planning is to determine the generating capacity required to satisfy the electrical load in a reliable manner during a given period of time. One of the most up to date approaches for fulfilling this objective is to rely on probability analysis to calculate the risk of not being able to meet the forecasted peak demands. One measure of this risk is called the Loss-of-Load Probability (LOLP) and it has been the traditional criteria used by PREPA for determining the need for future generating capacity. The risk or reliability criteria which has been adopted is that new capacity has to be added to the system whenever the LOLP falls below the 1.00 days per year mark.

Using the LOLP computer program, one generation expansion pattern was developed. This pattern (Base Pattern) is a mix of 300 MW Coal units and 370 MW Combined Cycles units. Other patterns were developed by exchanging the first 300 MW Coal unit after 1987-88 with a different type of unit. These new patterns were then evaluated, using the LOLP computer program, to determine the risk achieved year by year after the change of unit, for the expected energy not served due to the change in risk, and for the economic impact due to the energy not served.

Each pattern was then evaluated economically, by using the Production Cost computer program, for determining the system production cost, investment cost, outage cost and total cost. Of course, the results of the evaluation will be as good as reliable the load forecast may be. Also important are the expected costs of the fuels to be considered, as well as the pertinent costs and operating characteristics of the generating units to be considered.

RESULTS

Production Cost. Production cost for the system consists of fuel cost, operation and maintenance cost, start up cost, and fuel inventory cost. By changing the first 300 MW Coal unit, after 1987-88, by a 450 MW OTEC 5%* unit the most economical pattern, production cost wise, was obtained. This pattern was followed by the OTEC 10% and OTEC 15% patterns. As expected, Oil was the most expensive alternative.

Investment Cost. At 92.076 million dollars per year (levelized investment cost) the Base Pattern was the most economical choice followed by the Oil and Nuclear patterns at 93.385 and 104.228 million dollars per year, respectively. The OTEC alternative was 135.729 million dollars per year.

Outage Cost. Outage cost, a new ingredient in PREPA economic evaluations, is a function of system reliability. The most economical option is OTEC 5% followed by Nuclear and OTEC 10% at 8.753, 9.539 and 9.865 million dollars per year respectively.

Total Cost. Total cost is the sum of production, investment and outage costs. For the six patterns evaluated, the most economical choice is the Nuclear pattern with a total levelized cost of 1,035.225 million dollars per year, followed by OTEC 5% and OTEC 10% with 1,052.288 and 1,058.634 million dollars per year respectively.

CONCLUSIONS

Based on PREPA's assumptions, the Nuclear unit in 1992-93 is, by a small amount, the most economical choice for the system. The closest competitors, OTEC 5% and OTEC 10%, are only 17.063 and 23.409 million dollars per year away respectively. Although OTEC is a non-fuel consuming unit, the high investment cost of this alternative makes the difference between the OTEC and Nuclear options.

* Per cent figure corresponds to the assumed forced outage rate.

CONCEPTUAL DESIGNS FOR COMMERCIAL
OTEC-AMMONIA PRODUCT PLANTSHIPS

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EXTENDED ABSTRACT

There is now general agreement among major investigators that delivery of Ocean Thermal Energy Conversion (OTEC) electricity to island markets (e.g., Hawaii, Puerto Rico) by cables will be cost-competitive with electricity from oil-fired power plants as soon as the first commercial-size OTEC plants can be built. We believe that development of cruising OTEC plantships to tap the enormous ocean thermal resource in millions of square miles of tropical oceans near the equator is even more important. Use of OTEC electricity to make energy-intensive products such as ammonia at sea could significantly reduce U.S. dependence on foreign oil. The U.S. OTEC program has gained momentum through Public Laws 96-310 and 96-320 by which OTEC pilot/demonstration plants could be in operation in the mid-1980's followed closely by commercial-size facilities and plantships. Ammonia product plantships could be commercially competitive with ammonia made from natural gas or coal in the late 1980's[1]. A recently completed baseline design for a 40 MW_e (nominal) 125-short-ton/day, OTEC/ammonia pilot/demonstration plantship including folded-aluminum-tube[2] and/or plate-type titanium heat exchangers (HX's) confirmed projections of costs and (estimated) production capacities.

Ammonia is a major industrial chemical used mainly for nitrogen fertilizers. Its production consumed 630 billion ft³ of natural gas in 1978, equivalent to 300,000 bbl/day of oil. It can be synthesized at sea using nitrogen extracted from the air via partial air liquefaction and hydrogen obtained from distilled seawater by electrolysis. It can also be decomposed again on shore to regenerate the hydrogen for use in fuel cells to generate electricity anywhere in the world.

Reynolds Metals and TRW are investigating OTEC production of aluminum by various processes[3]. Examples of product options which have received less attention to date include strategic metals such as nickel and molybdenum, liquid hydrogen (LH₂), methane, methanol, various specialty fuels, "sea chemicals" (e.g., NaOH, KCl, Mg, and Cl₂ and organic chemicals). "Energy-bridge" systems could include lithium-lithium hydroxide and aluminum-aluminum hydroxide for battery systems. This paper addresses plantship designs for the most promising and versatile product, ammonia. Nearly identical plantships could be used for the production of LH₂, methane, or methanol[4].

A planform sketch of a commercial plantship of 360-MW_e (net) output, Fig. 1, features twelve 30-MW_e (net) power modules, arranged in groups of four; each group is served by a 50-ft-diameter cold-water pipe (CWP). Use of three CWP's facilitates cold water distribution on the platform and avoids the need for

a pipe diameter greater than 50 ft, which may be near the practical limit for constructibility and handling. With this arrangement, shutdown of one seawater pump or one heat exchanger set (2 each of 5-MW_e evaporators and condensers) for system maintenance will reduce plant output by only 2.7%.

The detailed arrangement of the power system including the seawater pumps and seawater distribution channels is a crucial part of the design. The sizes and placements of the ammonia turbines, pumps and auxiliary equipment in relation to the heat exchangers is shown in Fig. 2. Alternative types of aluminum HX's or any non-aluminum HX's that appear to be cost-competitive on a lifetime basis and have similar installation/water flow requirements may be substituted in this layout. Another important consideration is selection of turbine and HX module sizes and placements and design of control systems that will minimize the effects of oscillating loads and output power to the process load. The process plant and its controls must be tailored to accommodate seasonal variation in OTEC power output as well as variations incurred during moderate storms (wave heights < 18 feet) or shutdowns of individual power modules for maintenance, repair or replacement of a component. The plants must be designed to survive during once-in-100-yr storms (significant wave height of 29 ft) but would be shut down whenever waves exceed 18 ft (~ 0.5% of the year).

As noted earlier, LH₂, methanol, and methane process plants could have modular platform designs similar to that shown in Fig. 1. Use of essentially common power-plant/designs for several products would have the strong beneficial economic effects that can result from learning through repetitive production in a few competing manufacturing facilities and shipyards. To ensure that versatile, economical plantship concepts are developed, parametric variations in layouts of power system, electrical, and process plant equipment are being considered including integrated product storage, and common power system/process plant auxiliaries.

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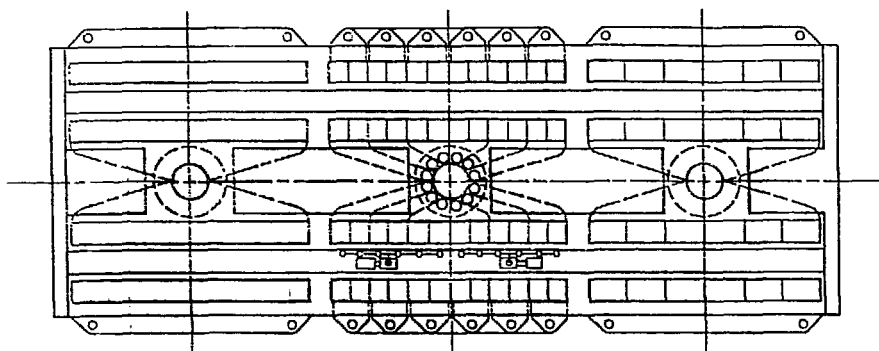


Fig. 1 Conceptual Layout of 360 MW_e(net) - 1100 MT/day Ammonia Plantship
Three-50 ft. diam. CW Pipes - Twelve-30 MW Turbine/Generators -
144-5 MW_e (net) Folded Tube HX

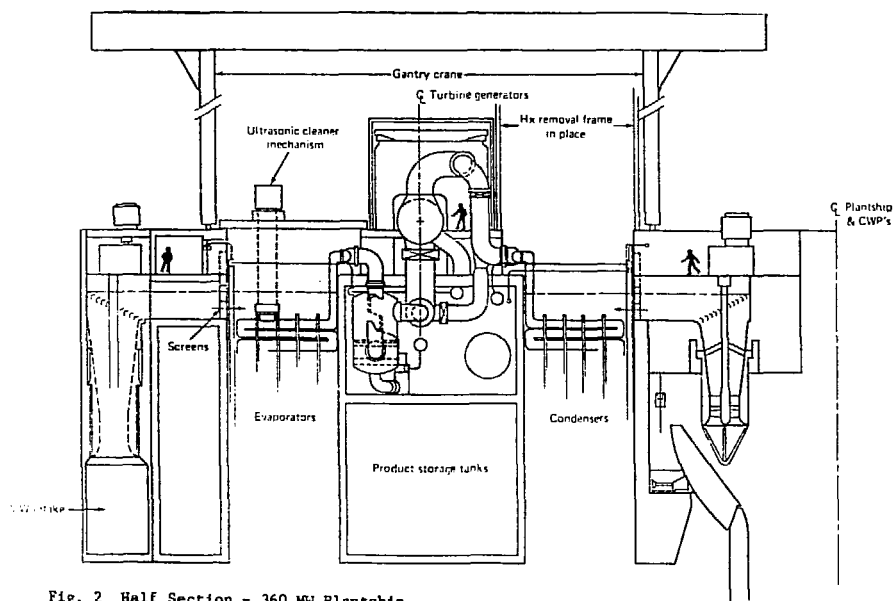


Fig. 2 Half Section - 360 MW Plantship
30 MW_e (net) Turbine Generators - 10 MW_e (net) SW Pumps & HX Pairs

ALUMINUM INDUSTRY APPLICATIONS FOR OTEC*

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ABSTRACT

The objective of the program is to study the integration issues which must be resolved to realize the market potential of ocean thermal energy conversion (OTEC) power for the aluminum industry.

The study established, as a baseline, an OTEC plant with an electrical output of 100 MW_e which would power an aluminum reduction plant. The reduction plant would have a nominal annual output of about 60,000 metric tons of aluminum metal. Three modes of operation were studied, viz:

1. A reduction plant on shore and a floating OTEC power plant moored offshore supplying energy by cable or pipeline.
2. A reduction plant on shore and a floating OTEC power plant at sea supplying energy by means of an "energy bridge."
3. A floating reduction plant on the same platform as the OTEC power plant.

For the floating OTEC/aluminum plantship, three reduction processes were examined.

1. The conventional Hall process with prebaked anodes.
2. The drained cathode Hall cell process.
3. The aluminum chloride reduction process.

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DEVELOPMENTAL TESTING OF A CONCRETE COLD WATER PIPE FOR OCEAN
THERMAL ENERGY CONVERSION (OTEC) SYSTEMS

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EXTENDED ABSTRACT

SUMMARY

A 1/3 scale model of the lightweight concrete Cold Water Pipe (CWP) for a 40 MW_e (nominal) pilot plantship was fabricated and tested to destruction. The model was 10 ft in diameter, with 2-in-thick reinforced concrete walls and 3-in-thick post-tensioning channels. It had an overall height of 17 ft including the scaled hinge region in the center. The operation of the hinge joint was verified and the stiffness of the joint was experimentally determined. The model was then loaded by increments until failure. Failure occurred at a load approximately 38% greater than the design load that would occur at 100-yr storm conditions.

INTRODUCTION

A 40-MW_e (OTEC) pilot plantship will require a 30-ft-diameter, 3000-ft-long cold water pipe (CWP). A design concept based on the use of a lightweight structural concrete has been developed. To reduce stresses and facilitate deployment, this concept includes a joint every 50 ft. The joint concept utilizes shear deflection of Neoprene pads located every 30° around the periphery of the joint. The pads allow the joint to rotate approximately 1° about any axis. The Neoprene material is similar to that used in joints to allow thermal expansion of suspension bridges and viaducts.

The concrete has a fresh unit weight of 82 lb/ft³ and a design compressive strength, f'_c , of 4600 psi. Analytical predictions of the dynamic motions of the pipe using the Paulling segmented pipe computer code [Ref. 1] were used to generate a set of limit loads, which were scaled and used to design a 1/3-scale pipe. One segment of the scaled pipe was fabricated and statically tested to destruction. The project addressed five major task areas:

1. Develop the analytical models needed for pipe design.
2. Conduct tests of bearing pads, shear reinforcement, post-tensioning anchors, and shear tests of full-scale reinforced concrete corbels.
3. Determine whether the lightweight concrete can be successfully mixed and placed by production personnel.

4. Measure the rotational, axial, and shear stiffness of the joint and compare results with finite-element computer predictions.
5. Verify the structural computer models used to design the pipe by constructing and testing to destruction a 1/3-linear-scale segment while measuring deformations, stresses, and strains. Modify the computer models, if necessary, to reflect the test results.

MODEL DESIGN, INSTRUMENTATION, AND LOADS

The model was designed to be geometrically similar to the prototype CWP. If λ is the scale factor for length (1:3) then force scales by λ^2 (1:9) and moment scales by λ^3 (1:27). Both strain and rotation are non-dimensional and not affected by scaling laws. Since this was a static test, the fact that gravity was not properly scaled has a negligible effect. The loads were applied by four vertical hydraulic rams acting against the end blocks and reacted through the pipe. The steel frame structure supported only the dead load, not the test loads. Shear loads were applied by separate hydraulic rams acting on cables which extended diagonally from one end block to the other. Any combination of axial load, moment, and shear could be applied to the specimen by balancing the pressures in the six hydraulic rams. Applied loads, absolute deflections, deflections of one section relative to the other, and strains in key areas of the concrete and the steel rebars were measured. Strain gages were applied to the rebars prior to casting both specimens and to the concrete surface after assembly. Unfortunately, none of the gages attached to the post-tensioning cables survived the grouting of the post-tensioning ducts.

The design loads were calculated using the Faulling computer code and the Bretschneider spectrum of the "100-yr storm" ($H_{1/3} = 29'$, $T_0 = 18.0$ sec) in a region of the South Atlantic East of Brazil. The maximum loads occurred about 250' below the keel and were: axial load 728 kips, shear load 28 kips, rotation 0.68° , moment based on the predicted joint stiffness 802 ft-kips. The model was designed to these values, then tested beyond these values to destruction using the setup in Fig. 1.

RESULTS AND CONCLUSIONS

Ultimate failure occurred about 138% of design ultimate load when one of the circumferential post-tensioning cables in the bell segment failed, followed by considerable spalling and cracking in the bell area. No through cracking occurred in the cylindrical part of either pipe section. The maximum stress observed in the steel rebar was approximately 48,000 psi, still below its allowable stress of 60,000 psi. Other than some stress concentration cracks at the corners of the cut-outs, structural cracking occurred at the predicted load and in the predicted locations. The rotational stiffness of the joint was approximately 24% less than calculated due to an error in selecting the scale model bearing pads, but the pad performance agreed with corrected calculations.

Some major conclusions are: The analytical models used to design the specimens have been verified, the lightweight concrete can be mixed and placed by production personnel using normal procedures, for the most part normal design codes and conventions can be used with this material, expanded clay aggregate must be stored in a dry sheltered location to maintain its lightweight, and the concept of the elastomeric hinge has been verified. Some additional effort is needed to quantify pad properties at extreme loads, especially under dynamic loads.

ACKNOWLEDGEMENT

The work reported herein was sponsored by the Ocean Systems Division, U.S. Department of Energy. The lightweight concrete was developed by the Construction Technology Laboratory of the Portland Cement Association. The model design, construction, and testing were performed by ABAM Engineers, Inc. and Concrete Technology Corporation under the direction of The Johns Hopkins University, Applied Physics Laboratory.

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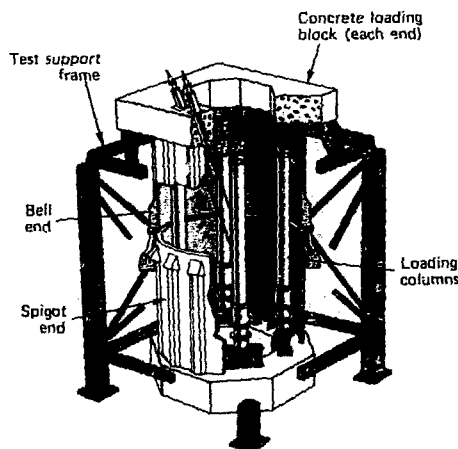


Fig. 1 Arrangement for one-third-scale tests of lightweight concrete CWP joints.

ALCLAD-ALUMINUM, FOLDED-TUBE HEAT EXCHANGERS FOR OTEC

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A potentially cost-effective option for Ocean Thermal Energy Conversion (OTEC) power plant heat exchangers uses 7.6-cm-O.D. Alclad aluminum tubes folded into tens of horizontal passes in a vertical plane¹. These planes (seven nested tubes per plane) are connected in parallel to form a heat exchanger module as illustrated in Figure 1 for a condenser. Seawater is pumped to a head pond above the module and flows downward by gravity to either evaporate or condense ammonia, the working fluid inside the tubes.

A "core unit" of this heat exchanger concept of 30-kW_e² size using three full-scale tubes was tested as an evaporator and as a condenser³ in order to establish a data base from which larger units could be designed. For the condenser the measured overall heat transfer coefficient was near 2900 W/m²-K at design conditions and varied with water flow Reynolds number to the 0.4 power but was nearly independent of the ammonia flow (Fig. 2). For the evaporator, the measured overall heat transfer coefficient was near 2250 W/m²-K at design conditions, and the data were correlated within +10% by a simple empirical expression (Fig. 3).

Acoustic radiation at ultrasonic frequencies is being investigated as a way to clean these heat exchangers. Experiments were conducted at Hawaii, in the Gulf of Mexico, and at APL using various ultrasonic cleaning devices to remove biofouling from aluminum tubes exposed to ocean water flows for periods from one week to 13 weeks. Data were gathered on exposure levels, times, and cleaning effectiveness to establish a basis from which a cleaning system for a full-size heat exchanger could be designed. Use of the ultrasonic mechanism allows power plant cleaning without shutting down and can be powered by less than 0.5% of the plant output. Results have indicated that a 15 second exposure once every two weeks at a surface intensity of 1 W/cm² at 20kHz keeps the average thermal resistance below 0.000035 W⁻¹m²K. The more persistent fouling that could accumulate over longer periods or in stagnant seawater could be removed by changing the mode of the ultrasonic cleaning from low-intensity continuous wave to higher-intensity pulsing at 10% duty cycle.

The Trane Company was contracted to (a) do the detailed design and construction of the APL core unit that was tested and (b) estimate the fabricability and price of an "nth" production

unit of the full-size design from the preliminary drawings and experience gained through manufacture of the test article. Using this information and the latest heat exchanger test results, which have been incorporated into the OTEC plant cycle analysis, APL has estimated a cost near \$400/kW_e for large-quality-production of the heat exchangers.

The full paper provides further details in each area. In summary, a low-cost, aluminum heat exchanger concept and a companion ultrasonic cleaning concept have been tested to a sufficient degree to indicate great promise for OTEC application. At-sea tests of the heat exchanger and development and demonstration of a prototype, plate-type ultrasonic cleaning device are needed as next steps for these concepts.

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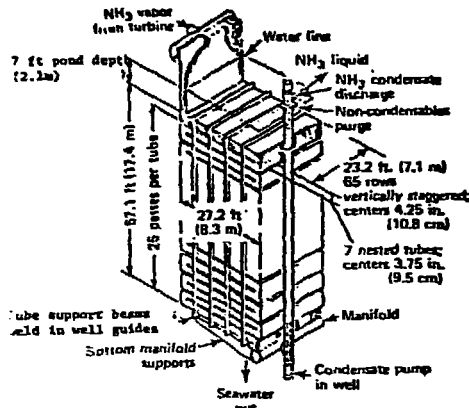


Fig. 1 5.0 MW_{net} condenser module having 2.4×10^5 ft² (2.2×10^4 m²) (nominal) surface area.

$$U = \left[\frac{1}{h_1} + \frac{d_1 \ln(d_2/d_1)}{2k} + \frac{d_2 \ln(d_3/d_2)}{2k} \right]^{-1}$$

$$U = \left[\frac{1}{h_1} + \frac{d_1 \ln(d_2/d_1)}{2k} \right]^{-1} \quad d_1 = 0.2387$$

$$d_2 = 0.2387$$

$$\frac{d_1 \ln(d_2/d_1)}{2k} = 0.000722 \quad k = 85.673 \text{ Btu/hr-ft}^2 \cdot ^\circ\text{F}$$

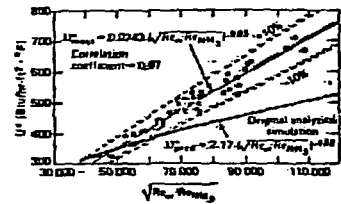


Fig. 3 Correlation of data for measured overall heat transfer coefficient in Evaporator Core Tests

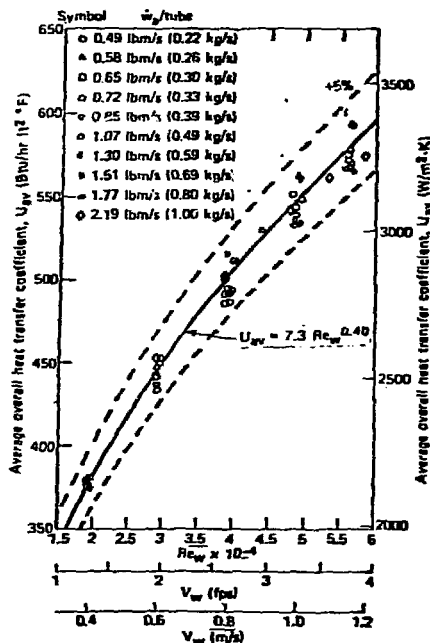


Fig. 2 Measured overall heat transfer coefficient (U) versus water flow Reynolds number (Re_w) and water velocity in minimum tube gap (V_w) for Condenser Core Test

THE FUTURE OF HYDROPOWER IN THE UNITED STATES

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EXTENDED ABSTRACT

In the current debate about the energy future of the United States hydropower is sometimes dismissed as an insignificant future source of energy or portrayed as a potential savior to rescue us from our energy crisis. These positions leave room for doubt as to the future of hydropower in the United States. However, the early results of the Corps of Engineer's National Hydropower Study (NHS) and related efforts by the Department of Energy have sharpened the hazy view of the future to give some insights into plausible hydropower futures. I used the information from these hydropower studies to forecast the role of hydropower in the nation's future to the year 2000. In doing so, I briefly described the history of hydropower in the U.S. as it relates to the current and future setting of the resource. Next, I discuss the current status of hydropower in the United States, both the existing resource and the estimated physical potential. The factors that will influence the development of hydro are many and complex. Thus, I've included a general discussion of these factors as barriers or incentives to the future of hydropower. Based on my assessment of these factors I've developed a high, low and probable forecast of future hydropower development in the United States to the year 2000.

Hydroelectric power provides about 14% of the nation's total electrical generating capability with an installed capacity of about 73,000 MW, including pumped storage. This amount of capacity produces an average energy generation of about 280 billion KWhr/year or about 3 quads*. On a regional basis hydropower accounts for over 40% of total electric capacity in the Pacific Northwest (including Alaska), 12% in the Upper Midwest, 10% in New England and less than 10% in the rest of the country.

Using the preliminary results of the NHS the total hydropower resource potential in the U.S. is about 512,000 MW in terms of capacity and 1.4 million GWhr in terms of energy. This includes 1,251 existing hydropower facilities. Incremental potential is defined as that available additional power at existing dams with or without existing hydropower facilities. Over 5,400 sites with additional capacity of 94,000 MW and energy generation of 223,000 GWhr are available at these incremental sites. Finally, there are 4,500 undeveloped sites which could generate 354,000 MW with about 935,000 GWhr.

*One quad equals 10^{15} BTU's.

The undeveloped category has by far the most potential and the most uncertainty. Very few large dams have been built in the past 10 years and to capture the undeveloped energy many would have to be built. Also, most of this potential is in Alaska far from demand centers. Little of this resource will likely be developed by the year 2000.

If all of the physical hydropower capacity potential available were to be developed it would double the existing electric capacity from all sources in the United States. Unfortunately, only a portion of this potential will ever be put to use. How much of the physical potential can be developed by the year 2000? The answer to this question depends on myriad factors affecting hydropower development. These factors are being analyzed in depth as part of the NHS. The cost of hydropower relative to other forms of generation, competition for water, environmental impacts and institutional impediments are the major factors that must be considered in deciding about future hydropower growth.

Table 1 present high, low and probable forecasts for additional hydroelectric power development by the year 2000. The forecasts consider development at both incremental and undeveloped sites as described in the inventory. The probable forecast predicts that 2,900 sites will be developed to produce an additional 65,000 MW of hydroelectric capacity and 158,400 GWh of electric energy. The forecasts have been made considering the information supplied by the inventory, factors affecting hydro development, possible scenarios associated with each one of the forecasts and plausible growth rates for hydroelectric power.

	EXISTING	YEAR 2000 ADDITIONAL HYDROELECTRIC POWER		
		PROBABLE	HIGH	LOW
NUMBER OF SITES	1,300	2,900	4,200	1,700
CAPACITY (MW)	63,700	65,000	94,600	35,500
ENERGY (GWhr/YR)	280,000	158,400	231,100	85,700

TABLE 1. Forecasts of additional conventional hydroelectric power development to the year 2000.

The probable forecast corresponds to a rate of growth of 3.5% for capacity and 2.2% for energy. These rates are slightly lower than the development rate for the last 60 years, but slightly higher than the rate for the last 20 years. On the one hand, available sites are becoming harder to find and more expensive, on the other hand the cost of alternatives to hydropower is making hydropower more and more attractive. Thus, these projected growth rates are reasonable. In addition, they are in close agreement to other recent forecasts of future energy sources.

By the year 2000 the total energy supplied by hydro could be 4-6 quads. If growth rate of energy slows down as expected, hydro should hold its current share of the electrical mix at about 12-14%. Many small-scale sites will be built in New England, navigation structures will be developed for hydropower on all major rivers and man-made structures to carry water will be fitted with turbines and generators. Only a small number of additional large scale projects will be developed over the next 20 years.

Hydropower development faces severe economic, environmental, social, institutional and financial barriers, but the rising cost of thermal sources and the unique attributes of hydropower will promote hydropower development. However, Congressional action will be needed to foster hydropower. The National Hydroelectric Power Study will supply data and develop options for consideration by Congress.

In connection with conservation, hydro can provide a symbol of the energy future of America as well as ease the transition to the solar age. Unfortunately hydro will do little to ease the current oil shortage, but it can do its part to reduce oil use to produce electricity. It is well for us to remember that the key to the energy future of the United States is in the wise use and conservation of all our resources. Hydropower, the nation's first large source of energy, must not be overlooked.

ADVANCES IN THE STATE-OF-THE-ART OF SMALL HYDRO ENGINEERING TECHNOLOGY

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EXTENDED ABSTRACT

INTRODUCTION

Engineering development is one of six subprograms which comprise the U.S. Department of Energy (DOE) national small scale hydropower program. In exploring advances in the state-of-the-art of small hydro engineering technology, this paper will restrict itself to activities undertaken through this subprogram. Although we continually find other agencies and individuals in increasing numbers turning their attention to small scale hydropower concepts, their contributions to advancing the state-of-the-art will only be included to the extent that they were sponsored by DOE as part of its engineering development subprogram. As is the case in most of DOE's small scale hydropower subprograms, DOE's role in engineering development is primarily one of financial assistance in support of concepts suggested to DOE in the form of either unsolicited or solicited proposals, with only a few of the early projects directly commissioned. One of the first projects, undertaken in 1977, when the national program was known as a low head hydro program, was an investigation of the state-of-the-art of low head generating equipment throughout the world. The Corps of Engineers and the former Bureau of Reclamation (now Water and Power Resources Service) were involved in other early engineering development projects through cooperative agreements with DOE. A recently published feasibility assessment guide manual resulted from one such project involving the Corps while the Bureau looked at such things as standardized inlet and outlet structures and power grid interties.

UNSOLICITED PROPOSALS

From a multitude of unsolicited suggestions and proposals for equipment development, in late 1977 DOE funded a project to perform model tests on a new turbine concept known as a Schneider engine. Last September (1980) DOE entered into a cooperative agreement with the Turlock Irrigation District in California to install a prototype Schneider engine in their main canal. Other projects which DOE has funded from unsolicited proposals as part of its engineering development subprogram include such concepts as the cost of controls for small hydroelectric plants or river systems, the use of pumps as turbines, automation and protection equipment specifications for small power plants, a pumped storage feasibility scheme for a town in Minnesota, and an assessment of the feasibility of generating electricity from tidal power in an inlet near the Bay of Fundy.

SOLICITED PROPOSALS

Thirteen additional DOE projects in engineering development are underway as a result of solicited proposals received in 1979 and 1980 and two proposal solicitations are currently being considered for fiscal year 1981. One solicitation being considered would seek proposals to install a turbogenerator system which would demonstrate the feasibility of retrofitting existing dams through the use of siphon penstocks. The other would solicit proposals for the establishment of an independent hydraulic testing facility within the U.S.

Program Announcement - In 1979 DOE issued a Program Announcement soliciting proposals to conduct engineering studies, research, and/or development of: (1) concepts for civil or structural modifications which would significantly improve the economic viability of retrofitting existing dams with hydropower generating equipment, and (2) innovative concepts to improve manufacturing processes and materials. Two projects are currently underway based on proposals received in response to that solicitation. One project is assessing the feasibility of establishing a central powerhouse construction facility on the Arkansas River where powerhouses can be prefabricated and floated into place behind various navigation dams along the river where they would then be sunk onto a prepared foundation and very quickly go into operation. The other project is being undertaken by Ingersoll-Rand where they are investigating the modification of a series of large vertical pumps to make them more efficient when operating in a turbine mode.

Program Research and Development Announcement - On April 7, 1980, a Program Research and Development Announcement was issued, soliciting proposals to conduct engineering studies, research, and/or development of concepts which would significantly improve the economic viability of the nation's ultra low-head (3 meters or less) hydroelectric resource at sites which have a power potential of 25MW or less. Proposals received in response to this solicitation have now been evaluated and, at the time of this writing, negotiations are underway in an attempt to fund eleven proposed projects. These projects involve such concepts as: hydraulic air compressors as part of an ultra low-head power system, ultra low-head crossflow turbine exploratory development, powerhouse - gate development, design of an ultra low-head package based on marine thrusters, demonstration of scroll motor advantages for ultra low-head hydroelectric power generation, asynchronous generator development, river current turbine development, modular hydro dam development, investigation of a Cherepnov lifter head augmentation device, modular innovations in upstream fish passage, and optimization of a diffuser/ejector for ultra low-head hydroelectric systems.

CONCLUSION

This paper briefly reviews the results of already completed DOE engineering development projects, explores the status of projects currently underway, and examines the prospects for near term future developments.

Development of Low Power Hydroelectric Sites

by

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ABSTRACT

The U.S. Army Corps of Engineers estimates there are over 5000 dams in the United States at which low power hydroelectric generating facilities might be developed. Many of these dams were built for flood-control or recreational purposes and have never been tapped for electricity. Others, designed to provide power for local mills and factories at the turn of the century were simply phased out during the era of cheap oil and big centralized power grids. The electric power generation potential of most of these dams taken individually is small; however, their combined potential is estimated at between 5000 and 6000 megawatts.

With increasing concerns for the nations dependence upon imported oil and the search for alternate energy sources, water power may be on the brink of a renaissance. Among the more attractive features of hydroelectric power are: the technology already exists, the environmental impact at an existing dam is negligible and the source of energy (falling water) is replenished at least on a seasonal basis.

The Department of Energy has established a program to encourage the development of small hydroelectric power projects at the site of existing dams which are not currently being used to generate electric power. The program is specifically directed at projects which will have an installed capacity between 100 kw and 15,000 kw. The Secretary of Energy is authorized to make loans for defraying a major portion of a study to determine the feasibility of undertaking a small hydroelectric project at an existing dam.

The City of Tuscaloosa (Alabama) is currently involved in a feasibility analysis of a hydroelectric facility located on a city owned reservoir, Lake Tuscaloosa. The author is project manager for this study. Experiences with establishing the feasibility of a small hydroelectric facility will be discussed. Current economic considerations, available equipment, design criteria, disposition of the generated power, and other factors influencing the development of a small hydroelectric facility will be discussed. Experiences with the Department of Energy, Federal Energy Regulatory Commission and other regulatory agencies will be summarized.

POWER SYSTEM PROBLEMS ASSOCIATED WITH LOW-HEAD
HYDROELECTRIC UNITS

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EXTENDED ABSTRACT

INTRODUCTION

Our supplies of oil and natural gas are rapidly decreasing. Coal and nuclear energy, though plentiful, have continuously been plagued by environmental and regulatory problems. As a result, there is renewed interest and enthusiasm for developing renewable energy resources. Low-head hydro is one such energy resource that has been receiving considerable attention from government agencies, utilities and turbine-generator manufacturers.

In addition to the economic, environmental and regulatory problems, there are unique power system problems associated with low-head hydro generation. One major reason for this is the dispersed small scale generation which is a characteristic of low-head hydro. Several power system problems thus need to be addressed very carefully in order to evaluate this renewable resource. Various aspects of these problems include:-

- (a) Transmission and distribution credit;
- (b) Frequency, voltage and power factor control;
- (c) Operating reserve;
- (d) Unit commitment;
- (e) Stability; and
- (f) Distribution automation control.

The purpose of this paper is to explain how the inclusion of low-head hydroelectric units in a power grid influences the above-mentioned aspects of power system operation. At the beginning, different types of low-head hydro turbine-generators are discussed briefly. Special, and sometimes unique circumstances under which some of these units have to perform, have important bearings on the selection of hydro-turbines, and ultimately on the overall plant operation. Subsequently, various aspects of power system operation are discussed in the light of widespread low-head hydro generation.

TYPES OF TURBINES

A low-head hydroelectric unit is taken to be the one with less than 15MW of electrical generating capacity and with an operating head of less than 20 meters. Due to the small head, vertical turbines appear to be less

effective for low-head hydroelectric units. The idea of placing the turbine horizontally in the water stream, however, has been found to be quite effective. Three types of such turbines presently being used are - tube, bulb and straflo.

Tube Turbine

Generally, a tube turbine is placed horizontally and coupled to the generator placed downstream. This type of unit is recommended for two principal applications. (1) Low-head (up to 15 meter) installations with up to 5000 kw capacity which generally operate unattended. (2) For rehabilitation of old low-head plants where the physical constraints favor the tube type.

Bulb Turbine

The bulb unit is of very compact structure in which the generator is contained in a water-tight steel housing shaped like a bulb. The generator is coupled directly to the high specific speed turbine. The entire unit is completely submerged and is placed horizontally in the water passage. This type of generator has comparatively smaller stator and rotor diameters for its MVA rating. This results in a design with relatively low voltage windings, low inertia constants (H), pressurized cooling systems, and small rotor air gaps.

Straflo Turbine

The outer rim of the turbine forms the generator rotor and carries the poles. The turbine and generator form one unit and the water flows straight through. Various advantages of the straflo turbine over the other types include - (i) no driving shaft, (ii) compactness, (iii) sufficient space around the runner periphery for generators of large capacities, (iv) simple and effective generator cooling and (v) large natural inertia.

Inertia Constant (H)

This is an important parameter in determining the stability of generator operation. Following is a comparison of inertia constants for various types of turbine-generators having capacities of about 50 MVA.

TABLE I. INERTIA CONSTANTS

Type	Inertia constant, H (MW·Sec/MVA)
Conventional	3 - 3.5
Tube	3 - 3.5
Bulb	1 - 1.5
Straflo	3 - 4

Due to the lower inertia the bulb type unit appears to be less stable compared to other types of units. Therefore more elaborate switching mechanisms are necessary for protecting bulb type units.

POWER SYSTEM ANALYSIS

An analytical model having several buses, lines and generators is built for the purpose of analyzing the influence of low-head hydroelectric units in an electrical power system. This model is used for analyzing various aspects of the power system problem in two ways - first, without and then with low-head hydro generation. The capital cost of a low-head hydro plant is generally higher than that of an oil-fired plant. However, the attractive features of low-head hydro are lower production cost and lesser dependence on non-renewable energy. Therefore, the economics of this kind of renewable energy source must be examined in the light of what type of energy source it is replacing. For example, the replacement of oil-fired generation may be more desirable over coal-fired generation. For this reason the power system model developed here is set up in such a way that the low-head hydro generating scheme can be compared individually with any other kind of conventional scheme, like coal, oil, gas or large hydro.

Another aspect of the power system analysis is the effect of a large number of low-head hydroelectric units in a system. For example, the effect on various aspects of the power system (as outlined earlier) is minimal when the generation mix consists of small amount of low-head hydro. Therefore a simple extrapolation is not possible to evaluate a substantial amount of such units in a power system. The power system model developed here can be used for resource substitution. In other words, comparative analyses can be carried out for varying amounts of low-head hydro generation in the system.

CONCLUSIONS

This paper presents a discussion on various types of low-head hydro turbine-generators and an analytical model for comparing various types of generation. The possibility of making a one-to-one comparison between low-head hydro and other types of conventional generation is very useful for technical evaluation.

ABSTRACT

TOWARD NEW INSTITUTIONAL RELATIONSHIPS IN
THE DEVELOPMENT OF SMALL SCALE HYDROELECTRIC POWER

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Small scale hydroelectric power (SSH) at existing dam sites and impoundments throughout the United States has attracted considerable interest from a variety of sectors of the public. In many areas, for example the Northeast and the Pacific Northwest, SSH is an important resource for meeting energy demands in the 1980's and 1990's. However, hydroelectric power comes to troubled 1980's with considerable regulatory baggage. Of all of the renewable energy resources which are technologically and economically feasible at the present time, SSH is probably the most highly regulated resource. Fortunately, regulatory and institutional relationships involving SSH are changing and changing quite rapidly.

This paper will examine the changes in institutional and regulatory relationships in small scale hydro power within four major areas; (1) licensing at the federal and state level; (2) environmental regulation at the federal and state level; (3) marketing and access to markets; and (4) subsidies and other monetary incentives.

With respect to state licensing and federal licensing, the

Federal Energy Regulatory Commission (FERC) has undertaken major regulatory initiatives in the last two years to expedite the licensing process. The paper will discuss these regulatory initiatives. In response to FERC reforms of the licensing process, several states have undertaken to reexamine their licensing systems to make them more efficient and more easily understood. The paper will also discuss certain state regulatory initiatives.

There is a growing body of literature on the environmental impacts on small scale hydroelectric facilities. The original consensus that small scale hydroelectric resource facilities have significantly less environmental impact than other potential sources of energy, with the possible exception of conservation, is probably still accurate. However, this growing body of environmental literature has identified certain environmental problems associated with small scale hydroelectric facilities. Specifically, reservoir stratification and the attendant release of the oxygenated water and ironized trace metals in downstream tributaries have caught the attention of environmental scientists. With major anadromous fish restoration programs in progress throughout the United States, small scale hydroelectric facilities obviously are a barrier to upstream and downstream migration of such fish. The design of fish passageways to permit upstream and downstream migration is an important facet of SSH development. More importantly, a major policy decision must be made with respect to which segment of the public bears the cost of the installation of fish passageways.

Until the enactment of the Public Utility Regulatory Policies Act of 1978, small scale hydroelectric developers faced the classi-

cal monopsony market controlled by investor and publicly owned utilities. To a great extent Title II of PURPA deals successfully with this market imperfection. However, the success of PURPA turns most importantly on implementation of federal regulations by state public utility commissions and publicly owned unregulated electric utilities.

The final issue is whether or not to subsidize small scale hydro and how one measures the subsidy. Again, developments are preceding apace with respect to subsidies and other incentives for small scale hydro. Just recently, the Windfall Profits Tax legislation was enacted, which legislation contained major tax incentives for small scale hydroelectric development. Other programs, such as the DOE loan program and the Rural Energy Initiatives of the President will have been in place for almost two years by the time this paper is delivered. At that time, the success of these other programs may be evaluated as well. States are also experimenting with subsidy programs and it will be interesting to note the reasons why states have entertained their subsidy program and the nature of these subsidy programs.

ULTRA HEADLESS HYDRO POWER

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EXTENDED ABSTRACT

Earlier this year the USDOE, through its Idaho Operations Office, solicited proposals for innovative, economical, low head hydro power plant idea development. For this purpose, low head was defined as 3m or less. Early hydro power projects were small scale and very close to load centers. Inefficient paddlewheels turned shafts in mills which, through belts, drove mill equipment. With the advent of electrical power, hydro power projects could be reasonably remote from load centers and located at optimum sites of high head and intermediate flow or high flow and intermediate head. The best sites were quickly exploited and secondary sites became uneconomical.

Secondary sites or those even more remote from load centers were then exploited by public agencies and the economics justified by power generation plus flood control and/or irrigation plus establishment of potable water reservoirs, to serve rapidly growing urban centers. Many of the earlier dams no longer were used to generate power as the mill-races vanished. Many new low head dams were used for flood control and evening flows toward hydro power projects, and were not furnished with generators since these sites were even more remote from load centers. Also, such low head dams could not compete with modern, efficient steam-electric plants firing fuel costing less than \$2 per barrel of oil. The rekindling of interest in low-head hydro power is a natural result of the skyrocketing costs of fossil and fissionable fuel, since hydro power of any capacity is derived from a free energy source. This revived interest is still chained to electrical concepts of the recent past such as 60 Hz generators.

In general, low head hydro power runners have a low rotary speed requiring many tens of wound poles and closely governed speed control which makes such equipment cumbersome and expensive. Prior to high cost fuels, numerous studies were made of tidal power projects as at Passamaquoddy, Maine. All of these were considered "no go" by a plurality of experts due to the expected high cost of very low head turbine-generators and breakwaters which would have created a head commensurate with the 3m or less referred to above. Low head hydro power turbine-generators have been used to harness tidal energy in France and to replace very inefficient original equipment using tube turbines which can be inserted into many existing penstock-tailrace arrangements. All of these efforts, while expanding generating capacity, do not approximate the potential benefits of ultra headless hydro power. The limit of an ultra headless state is zero head which is impractical because when head is zero there is no flow. The ultimate attainment of hydro power from least head requires that flows be very large and heads be the velocity head that creates the flow velocity.

This leads to a necessary digression. How do we store electrical energy? There are many ways, most of which are impractical or very expensive. One very practical way is to use electricity to dissociate water into its

constituent gasses, hydrogen and oxygen. These can be stored under high pressure, chilled to cryogenic temperatures to reduce bulk or, in the case of hydrogen, transformed temporarily into hydrides of small bulk but no pressure.

The fuel value of electrolytic hydrogen is equal to the electrical energy used in low temperature cell banks. If the initial energy source is free (hydro, geothermal or solar, for instance), the hydrogen and oxygen gasses can be stored for shipment and be recombined later to release the stored chemical energy. Hydrogen gas can also be combined with nitrogen gas to form liquid ammonia or gaseous carbon monoxide to form liquid methanol to simplify shipment and end-use. As a fuel, hydrogen contains three times the fuel value per kg of petroleum fuels and four to five times that of coal. Hydrogen burns to water vapor in the presence of oxygen, and as a gas is less dangerous than most contemporary gaseous and liquid fuels. It is very fluffy and, if leaked, will rapidly rise to buoyancy equilibrium at an altitude of about 20km.

If the electrolytically pure oxygen is also saved and recombined with gaseous hydrogen, this firing can take place in the most efficient and least costly of fuel cells having no fuel preparation section, boilerless steam turbines, and compressorless gas turbines. In each case, some of the effluent steam and/or water would be recycled to maintain temperatures within hydrogen age power equipment just under the maximum levels which can be tolerated.

The use of electrolytic hydrogen to store power releases the generation of electricity from the need for 60 Hz or constant generator rotor RPM. The exciter can be shaft-mounted and arranged to generate alternating current which can be changed to direct current using a solid-state shaft-mounted rectifier for use in the main rotor field current windings which will be rotated at varying speeds dependent on water velocity. The stator coils will generate alternating current power of varying frequency, voltage and amperage. Output power will be converted to constant voltage, direct current electricity of varying amperage using a solid state rectifier. The electrolytic cell-banks will then produce hydrogen and oxygen in direct relation to the direct current throughput at a rate of 28.3 m³ of hydrogen gas per 63,000 ampere-hours.

The hydro power runners to accomplish the above generation can be of optimum design to derive power from large flows of fast currents of water. These could be of conventional design if used to capture the vast hydropower resources of Greenland which have many high head water run-offs on the ice-free east and west coasts [17]. To derive energy from fast-flowing rivers, swift-flowing ocean currents or tidal eages having ultra low head requires water wheels of novel design akin to windmills.

Windmill wheels can be the multi-vane type where tip speed equals wind speed and blade coverage of the wind throughput path is fairly complete, or the airplane propeller type where tip speed exceeds wind speed by a factor of six or seven and blade coverage is fairly incomplete. Early versions were short radius multi-vane wheels used to pump water on farms and long

radius one, two or three-bladed propellers shaped in accordance with aerodynamic principles used to generate electricity on a small scale. Other designs are less efficient and of less interest.

The efficiency of the multi-vane type wheel is about 30% while the best of the airplane propeller types is close to 47%. The possibility of using a hybrid type was discussed in an earlier paper ^[2]. This would call for an egg-crate construction to provide structural strength at higher tip speeds, and to contain multiple rows of blading with each row preset to achieve a good attack angle. Water flow velocity through blading could be increased at minimum hydraulic drag using fore cones and after cones to form a Venturi section.

A recent article on propellers noted that the principles of design of the propellers used to drive the superliner Queen Elizabeth II and the Gossamer Albatross were the same despite the tremendous difference in weight, area coverage and appearance ^[3]. This article went on to elaborate on current investigations which could result in propellers with many gull-wing-shaped blades having 70% area coverage being used to pull airplanes through the air at 80% of the fuel expended by fan-jet power plants at the same speed.

The use of these principles could lead to watermill wheels of immense size. These would have to be prefabricated in sections sized to allow shipment to the power plant site. There they could be welded together or equal to form wheels of very large diameters. When used with fore cones and after cones having two times wheel diameter, water velocity is increased by four and power output is 64. Fore and after cones can be stiffened by stranded stainless steel cables stretched from flange to flange. The fore cone inlets should be screened to prevent entry of heavy logs, mammals and large fish.

The optimum arrangement would have stators with a diameter somewhat larger than the wheels, and main generator rotors with a diameter slightly larger than the wheels. This would make lines of force-cutting speed equal to tip speed and optimize the use of a rigid structure needed between two wheels (or more) on the same shaft. By large wheel diameter, tens of meters is meant. Such wheels could generate over a 1,000 MW per pair, be suspended from barges anchored in the gulf stream, for instance, with hydrogen gas production cells mounted on the barges.

What is true of watermills is applicable to windmills. Unfortunately, air has a density less massive than water by a factor of 832 at standard conditions, and windmill outputs will be correspondingly lower. Watermill wheels could also be located on land in white water rivers and in tidal eages. Here the wheel diameters would be necessarily less and power output per unit correspondingly lower. Nonetheless, since head loss per unit is very low, and the number of units is not particularly limited, such plants could well be a useful adjunct to our overall generating capacity.

The watermills (or windmills) described above would have to be designed to withstand maximum fluid velocities, and this would produce electricity at

increased rates when such fluid velocities occur. This is not true of recent windmills which must turn tail and flutter when winds of 100 Km/Hr arise. Likewise, hydrogen production cell-banks cannot be overloaded, although production efficiency will drop when ultra low head currents are ultra swift.

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ON THE UTILIZATION OF THE RAM PRINCIPLE
FOR ECONOMIC POWER GENERATION AT LOW
VELOCITY HIGH VOLUME HYDRO SITES

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EXTENDED ABSTRACT

At the present time, high-volume, low-head dam sites are of limited utility for power generation because low-head turbines are economically impractical due to size. In the method we propose, conventional high-pressure turbines can be used at a low-head dam site by employing the ram principle. The basic task is to convert the high-volume, low-velocity system to a lower-volume, high-velocity system. Such a transformation is regularly performed by the conventional "gear box" or electrical transformer. The hydraulic analog of the gear box exists too, but involves complex designs with the very moving parts we are trying to avoid.

This paper discusses a hydraulic analog of a technique commonly used in pulsed power machines to achieve such a transformation with negligible moving parts. Specifically, a variation of the hydraulic ram will be discussed to show that the capital cost of such an approach is quite favorable. In addition, comparison of dam construction and area utilization will be covered. It is also shown that several low-head power generating systems of this design are more economical than one equivalent high-head system.

ANALYSIS OF A SMALL SCALE RURAL HYDROPOWER UNIT

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EXTENDED ABSTRACT

INTRODUCTION

Utilization of small and local energy supply systems using renewable energy resources draw more attention in developing countries. Only 18% of the hydraulic potential energy is utilized in Turkey by large hydro-electric systems. This paper presents a vertical axis water-wheel, named as EKE waterwheel. It has tilting vanes which practically eliminate the counter-drag during rotation of vanes. The paper includes theoretical analysis and experimental findings which indicate an efficiency of about 32%.

EKE WATER WHEEL

"Eke" is the last name of a Turkish Engineer who proposed a special waterwheel. This waterwheel seems to have its originality due to the radial vanes with tilting ability during their rotary motion in the flowing water. The yearly hydropower potential of Turkey is around 105×10^9 kw.H. 77×10^9 kw.H. of this potential is considered to be economically feasible. Although waterwheels have low efficiencies, their simplicity, ease of maintenance and low cost have regained their popularity in developing countries especially after the energy crisis. The basic advantages of the EKE waterwheel are:

- 1- Insensitivity to the direction of flow,
- 2- No practical limitation on flow rate,
- 3- Non-existence of any important counter-drag effect during rotation,
- 4- No pondage requirement.

The waterwheel has three basic components. These are the axis structure and Supports, frames, and Vanes, Vanes are supported along upper edge to the radial frames by means of hinges. Frames are fixed to the axis system. The axis system is supported by bearings both at its bottom end and top end.

ELECTRICAL POWER GENERATION USING OSMO-HYDRO POWERTM SYSTEMS

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If concentrated brine is separated from "fresh" water or dilute brine by a semipermeable membrane, permeable to water and not salt, water permeates from dilute brine to concentrated brine. The driving mechanism in such a process is osmosis. The magnitude of water permeation flux across the membrane is proportional to the difference in the osmotic pressures of the two solutions. If the concentrated brine is at a hydraulic pressure ΔP higher than the dilute brine, the direction of water flux is still from dilute brine to concentrated brine, against the hydraulic pressure, as long as ΔP is less than the osmotic pressure difference, $\Delta \Pi$. The magnitude of the water flux in this case is, however, reduced and is proportional to the net driving pressure of $\Delta \Pi - \Delta P$. In this configuration the water permeates due to now what is called as, pressure retarded osmosis (PRO). In Osmo-Hydro PowerTM (OHP), the free energy of mixing of a dilute and a concentrated brine is harnessed by means of PRO. In this process, water permeates through a semipermeable membrane against a hydraulic pressure gradient, from a dilute salt solution to a concentrated salt solution, to produce pressurized mixed brine. Energy is obtained by depressurizing of mixed brine through a hydroturbine. Solar evaporation ponds are used to concentrate mixed brine for recycling.

The technical and economic feasibility of salinity gradient using OHP was investigated under two Department of Energy projects. Under one project, laboratory experiments were done to investigate several technological problems of such a system, including membrane compaction under high hydraulic pressures, salt polarization, and brine induced deterioration of membranes. The second project was concerned with the development of OHP systems for utilizing various sources of salt and water, and development of a system simulation model for salt/water OHP systems. Under this project preliminary performance estimates were made with a comprehensive model for OHP systems. The paper will discuss some of the pertinent results from these two projects. Encouraged by the findings of these two studies, the Department of Energy issued a contract to Ebasco/InterTechnology to design a 50 kW system. The results of our findings on Phase I of this project, which was completed in May 1979, would also be reported. Specifically, it will be shown that the capital cost of solar power generation using OHP systems is about \$4,000 to \$5,000 per net kW. Work is presently in progress on the second phase of this contract under which we are studying a closed-cycle OHP system. In this configuration, the spent brine from the hydroturbine is unmixed into a dilute brine and a concentrated brine by use of solar energy for recycling.

OPTIMAL SCHEDULING OF POWER SYSTEMS
WITH PUMPED HYDRO STORAGE PLANTS ADOPTING
NON-LINEAR PROGRAMMING TECHNIQUES

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EXTENDED ABSTRACT

INTRODUCTION

With each passing year, load demands in power systems are growing. To meet these demands without resorting to the costly expansion of base-load generating facilities, expanded peaking capacity may be needed. Pumped storage offers a uniquely effective answer to this need.

PROBLEM FORMULATION

In operating a power system with thermal plants and pumped storage ones, the basis for selecting and loading plants is the minimization of the fuel cost over a given interval of time (the dispatch interval), when taking into consideration that each pumped storage plant will operate as a pumping plant during a certain period and as a generating plant during another period. During the pumping period, the pumping storage plant may receive the energy required for pumping either from the power system in which it is integrated or from a neighbouring system. The formulation of the problem depends on the source of the energy required for pumping water.

The First Case: The pumping storage plants receive the energy required for pumping from the power system in which they are integrated. In such a case pumping periods and generation periods, when the pumping storage plants are used as generating plants, depend on whether there is a surplus or deficiency in available thermal power in the system. For a given load curve, the load dispatch should be carried out over the entire period which it represents including the pumpin as well as the generation periods of the pumped storage plants.

Considering the load curve shown in Fig. 1, and dividing the total dispatch period into a set of constant load sub-

intervals, the problem may be formulated as an optimization problem in the following form:

$$\text{Minimize } Z = \sum_{h=1}^a \sum_{k=1}^n F_{kh} T_h \quad \dots(1)$$

Subject to:

$$G_1 = \sum_{k=1}^n P_{k1} - \sum_{i=1}^n \sum_{j=1}^n P_{i1} B_{ij} P_{j1} - P_{R1} - \sum_{k=n+1}^{n+m} P_{pk} = 0 \quad \dots(2)$$

$$G_h = \sum_{k=1}^{n+m} P_{kh} - \sum_{i=1}^{n+m} \sum_{j=1}^{n+m} P_{ih} B_{ij} P_{jh} - P_{Rh} = 0 \quad (h=2,3,\dots,a) \quad \dots(3)$$

$$G_{wj} = \sum_{h=2}^a Q_{kh} T_h - \frac{T_1}{D_k} (P_{pk} - E_k) = 0 \quad (k=n+1,\dots,n+m), (j=k) \quad (4)$$

$$\text{and: } P_{kmin} \leq P_k \leq P_{kmax} \quad (k=1,2,\dots,n+m) \quad \dots(5)$$

The Second Case: The pumped storage plants receive the energy required for pumping from a neighbouring system. In such a case, the pumping period is determined by the duration of time during which the neighbouring system is ready to export electric energy. Therefore for a given load curve, the dispatch during the pumping period could be carried out independent of the pumped storage plants.

Considering the period during which the pumped storage plants are used as generating plants, and dividing it into a set of constant load subintervals, as shown in Fig. 2, the optimum dispatch problem during this period may be formulated as follows:

$$\text{Minimize } Z = \sum_{h=1}^a \sum_{k=1}^n F_{kh} T_h + \left(\sum_{h=1}^a \sum_{k=n+1}^{n+m} q_k D_k Q_{kh} T_h \right) \quad \dots(6)$$

Subject to:

$$G_h = \sum_{i=1}^{n+m} \sum_{j=1}^{n+m} P_{ih} B_{ij} P_{jh} - \sum_{k=1}^{n+m} P_{kh} + P_{Rh} = 0 \quad (h=1,2,\dots,a) \quad (7)$$

$$\text{and: } P_{kmin} \leq P_k \leq P_{kmax} \quad (k=1,2,\dots,n+m) \quad \dots(8)$$

In the two cases, fuel cost of thermal plants and the discharge rate of the turbines of pumped storage plants may be approximated as a function of the plant generation in the form of a polynomial of any order. It follows that the economic dispatch problem of power systems with pumped storage plants is a non-linear programming problem.

The paper gives a complete formulation of the problem with all its merits and suggests the solution techniques which may be used for its solution. A worked example is also given in the paper to prove the effectiveness of the suggested techniques and to compare their advantages and limitations.

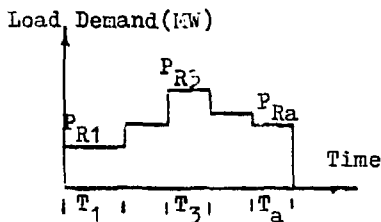


Fig. 1: A Typical load Curve

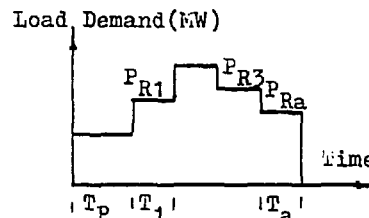


Fig. 2: A typical load curve

NOMENCLATURE

n, m	number of thermal and hydro plants respectively
a	number of subintervals in the dispatch period
T_h	duration of subinterval h in units of time
T_p	duration of pumping period in units of time in case 1
F_{kh}	fuel cost of thermal plant k during subinterval h in dollars/unit time
P_{ih}, P_{jh}, P_{kh}	generations of plants i, j, k during subinterval h in megawatts
P_{Rh}	load demand of the system during subinterval h in MW
B_{ij}	self and mutual loss-formula coefficients/MW
Q_{kh}	discharge rate of turbines of plant k during subinterval h in cubic meters/unit time
P_{pk}	input power to pumps of plant k in MW
Q_{pk}	cost of MWhr at the bus bars of plant k
D_k, E_k	coefficients of the straight line relation approximating the relation between the discharge rate and the input power of the pumps of plant k
Z	total fuel cost of the system during the dispatch period in dollars
P_{kmax}, P_{kmin}	maximum and minimum outputs of plant k in MW
T_p	duration of pumping period in the second case

OPPORTUNITIES IN WATER POWER DEVELOPMENT

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EXTENDED ABSTRACT

INTRODUCTION

Water power has been harnessed by men since several milleniums; however its large scale exploitation in form of electricity generation is basically accomplished during the last century. Nevertheless, during the last decades of this century, a large part of the world's nations will face serious problems related to energy shortages. In order to overcome these problems, all countries should take measures to minimize the losses in the use of energy, to maximize the exploitation of their conventional energy sources, and accelerate studies to produce commercial-scale energy from unconventional sources.

Water power is a clean and renewable, conventional energy resource. Furthermore, most of the water power schemes are often multi-purpose projects serving, besides hydroelectric energy production, to purposes like flood control, irrigation, navigation, etc.; so that they are considered as basic components of the socio-economic development from various perspectives. It should be put, therefore, special emphasis on the maximal exploitation of water power resources throughout the world.

In 1973, before the oil crisis effected almost all countries, the world's hydroelectric energy production was in the order of 1.3 thousand TWh/a and constituted a little more than one fifth of the world's total electrical energy generation of 6.0 thousand TWh/a. Furthermore the share of the primary resources allocated for the production of electrical energy to the world's total energy consumption is about 25%, so that the share of water power in total energy appears to be about 5%.

However, for many developed as well as developing countries, the importance of water power is much greater then the modest few percents representing its share in today's world total energy consumption. Moreover, water power is an almost inexhaustible energy resource compared to the finite reserves of conventional energy resources; and as stated above most of the water power schemes are often multi-purpose projects. Furthermore, it should be noted that in most developed, especially European countries, the harnessed part of the water power resources are larger than 60-90%, so that the bulk of the unexploited water power resources are in developing countries.

Within this broad scope of water power development, the paper will primarily focus on the assessment of water power potential, economic evaluation of water resources projects and the trends in water power exploitation.

ASSESSMENT OF WATER POWER RESOURCES

The water power potential of a region is usually expressed at three different levels, which can be used as indicators of the hydroelectric energy production capability of that river basin.

The gross hydroelectric potential, which can be considered as the theoretical upper limit of the hydroelectric energy production capability of a river basin, represents the gross potential of the head and water flow available in a year of average hydraulicity. Thus the gross hydroelectric potential is a function of the topography and the hydrology of the region, and should be considered virtually invariant with time, if these two factors can be covered satisfactorily.

The technically exploitable hydroelectric potential, which can be considered as the technological upper limit of the hydroelectric energy production capability of a river basin, represents the limiting value of the hydroelectric production after the implementation of technically possible water power schemes over entire region, excluding indispensable losses in head, flow and conversion caused by the state of the technology applied. Thus, the technically exploitable hydroelectric potential is a function and often a certain percentage of the gross potential and may also be considered as almost invariant with time, since sudden changes in water power technology has not occurred in the near past and is also not anticipated to occur in the next future.

The economically feasible hydroelectric potential, which can be considered as the economically optimal limit of the hydroelectric energy production capability of a river basin, is the total production of all water power schemes, which are technically possible as well as economically feasible. Contrary to the two foregoing potentials, the economically feasible hydroelectric potential may significantly change with time, being especially sensitive to changes in energy prices in general and to alternative electrical energy production costs in particular.

Generally, the technically exploitable potential is in the order of 30-50% of the gross potential; the economically feasible potential 20-25% of it.

Besides European and a limited number of other countries, these potentials are not accurately determined. Estimates are varying largely, for the world's gross hydroelectric potential from 44 thousand TWh/a to 80 TW power equivalent of 700 thousand TWh/a; for the economically feasible hydroelectric potential from 10 thousand TWh/a to 2,9 TW power equivalent of 25 thousand TWh/a; so that more detailed investigations are necessary for the dependable assessment of the water power resources all over the world.

ECONOMIC EVALUATION OF WATER RESOURCES PROJECTS

Basically, the economic evaluation encompasses the comparison of benefits accruing from and costs made for the development and operation of water resource schemes, within a given period of time and a discount rate reflecting the effect of the time. The decisions are made with regard to the results of this economic analysis and of the intangible welfare factors.

The criterion of choice in the economic evaluation of the optimal development plan is usually the adoption of the highest benefit/cost ratio or the highest net benefits. However, with regard to limited natural resources in view of the unprecedented fast growing of population and the even faster growing socioeconomic development, the selection of these criteria may result in an unefficient exploitation of the water power resources. This limitation leads to adopt a new criterion of choice, selecting the plan which provides the largest use of the water potential whilst having at least marginal economic feasibility and can be called a "maximization approach".

Therefore, the systems approach for water resources planning especially in developing countries where the larger part of the water resources has to be exploited in the future, is to search for solutions with an ultimate objective of maximum exploitation of the natural resource, providing initial "optimal" or even "maximal" stages, without violating the margins of economic feasibility. On the other hand, since these margins cannot be absolute by their very nature and the implementation of large water resources development plans requires up to several decades, the planning should be of sufficient flexibility in order to enable necessary modifications during later revisions.

TRENDS IN THE DEVELOPMENT OF WATER POWER RESOURCES

The increase of annual hydroelectric energy production of 55 countries with 1974 production exceeding 1 TWh/a based on available data during 1951-1974, are investigated for linear, logarithmic, parabolic and logistic trends.

The period of time required for the development of 95% of the economically feasible hydroelectric potential, between 2,5% and 97,5% of this figure, has been also investigated by the use of the aforementioned trend functions, based on data of 20 European countries, where this potential has been rather adequately calculated. These periods are further tested, whether they vary according to the hydroelectric potential of the country or to its level of development in 1974. The resulting periods range from 30-100 years, with the majority being around the average duration of 60-70 years.

The share of water power in total electrical energy generation is above 90% in countries like Norway, Ghana, Zaire, Iceland, Zambia, Brasil; around 70-80% in New Zealand, South Rhodesia, Sweden, Switzerland, Portugal, Canada, Peru, Nigeria, Albania. During the fifties and even sixties, the same high ratios were also in Finland, Italy, Spain, France, Austria; but decreased with regard to an almost fully development of the economically exploitable or a more rapid growth in alternative electricity production means resulted in the decreasing trend. Hence, after the oil crises of the seventies, many countries may aim at a high share of water power in electricity generation.

Thus, it can be expected that the last decades of this century and the early decades of the next may witness having a boom of water power development, especially in developing countries having significant hydroelectric potentials.

OCEAN THERMAL ENERGY -
THE HYDROGEN FUEL CELL CONNECTION

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ABSTRACT

Ocean thermal energy is one of the most vast resources of convertible energy in the world. Harvesting of this tropical ocean resource, by use of Ocean Thermal Energy Conversion (OTEC) plants to produce electric power, does not match geographically with electric power consumption centers. Using the electric power to produce hydrogen or a hydrogen carrier (such as ammonia) provides a means of transportation to distant users. A potential end use, which is highly attractive, is the hydrogen fuel cell which produces electric power.

There is a widening interest in fuel cells throughout the world, particularly for distributed applications and for peaking electric power. A recently constructed 4.5 megawatt fuel cell complex (fed by naphtha from which hydrogen is dissociated) is a milestone for this technology. Hydrogen derived from solar energy, as in the case of OTEC, provides a near term opportunity to displace petroleum-fueled peaking electric power generators through the fuel cell.

This paper discusses the state of the technologies involved and projects a future where fuel cells fed from OTEC provided hydrogen could provide an important energy technology. It is concluded that this is indeed a highly promising concept, and that specific steps are underway to bring it into being.

BIOFOULING IN SIMULATED OTEC EVAPORATOR TUBES ON AT-SEA
RESEARCH PLATFORM at PUNTA TUNA, PUERTO RICO

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ABSTRACT

During the past year a 115 feet by 34 feet Landing Craft Utility (LCU) has been modified and refurbished to serve as a biofouling, corrosion and materials research platform. The vessel was sailed to Puerto Rico and moored to a single point tension moored buoy in 3,400 ft. of water on January 17, 1980. After an at sea test of all components, the system start-up occurred on 29 January.

The facility consists of four (4) modules, each having an independent flow system. Each module is composed one Fetkovitch type instrumented pipe to obtain fouling resistance data and three (3) parallel flow, nine feet sacrificial tubes from which samples for biofouling and corrosion analysis are obtained. Two (2) of the modules consists of one (1) in diameter aluminum tubes and other modules are of titanium.

Fouling resistance data has been obtained on a weekly basis since start-up.

Approximately 70 biological and corrosion samples were collected each sample period for analysis either on-site, or at the laboratory.

Results of thermal fouling resistance, the nature of biofouling, and the extent of corrosion of simulated aluminum and titanium evaporator tubes are presented and the correlation among those results are discussed.

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MARINE MICROFOULING ON ALUMINUM AND TITANIUM HEATEXCHANGER
SURFACES AT THE CEER OTEC PUERTO RICO FACILITY

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INTRODUCTION

An OTEC biofouling experiment has been in progress since January 30 on a moored research platform off the southeast coast of Puerto Rico. The test facility used in this study consists of four independent experimental modules, each containing one heat transfer monitor (HTM) in parallel with three 1 inch (ID) simulated heatexchanger tubes. Two modules each tested 5052 aluminum and ASTM 3-338 grade-2 titanium tubes.

Fouling resistance (R_f) was determined using the Carnegie-Mellon type heat transfer monitors. Microfouling on the aluminum and titanium tube surfaces was analyzed on nine occasions during a period of 96 days. The first four samples were taken during the initial 17 days of the experiment (January 30 to February 15), the remaining five samples over the subsequent 79 days. Microfouling was assessed by determining the thickness and volume of the wet film, the amount of ATP, total surface residue, organic carbon, nitrogen and protein associated with these surfaces. Visual analysis of the exposed surfaces was made by scanning electron microscopy (SEM). The data reported here concern the wet film thickness and volume, carbon and nitrogen contents and the visual analysis of the materials found on these surfaces.

RESULTS

The fouling resistance of both types of surfaces slowly increased during the initial 18 days of the experiment (Figure 1). Following this, the R_f of the titanium surfaces increased linearly through 81 days of exposure. The R_f of the aluminum surface increased linearly through approximately 45 days of exposure at which point there was a change in the slope of the R_f function. After 81 days of exposure, the R_f of both surfaces abruptly decreased to near its original value. This spontaneous decrease in the fouling resistance was associated with the sloughing off of material from both test surfaces. [1]

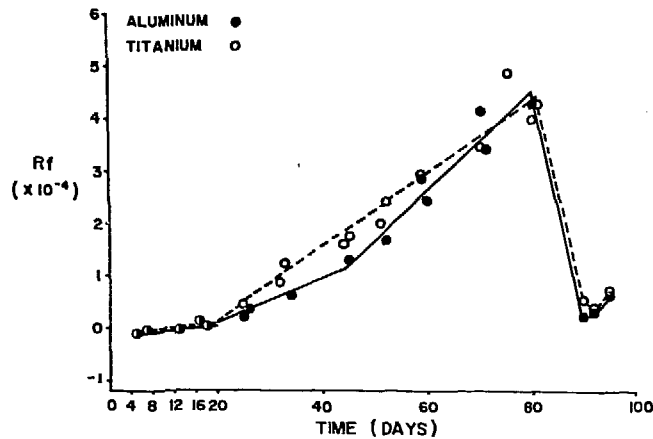


Fig. 1

Analysis of the wet film thickness indicated that there were three distinct phases of film development, (a) initiation (0 to 10 days), (b) maturation (16 to 40 days) and (c) bulk growth (50 to 95 days). These phases were characterized by the cyclic accumulation and loss of biomass on the respective surfaces [1]. This analysis is supported by the examination of the surfaces with SEM. The average wet film volume (WFV) on the aluminum surfaces increased with time of exposure in three distinct phases (Figure 2). The WFV on titanium increased linearly from 16 to 81 days of exposure. The average WFV on the test surfaces correlated well with the respective R_f values obtained (Figure 3). The volume of material on the titanium surface more strongly affected its fouling resistance than that seen on the aluminum surface. These differences are related to the organic carbon contents of the materials found on the test surfaces.

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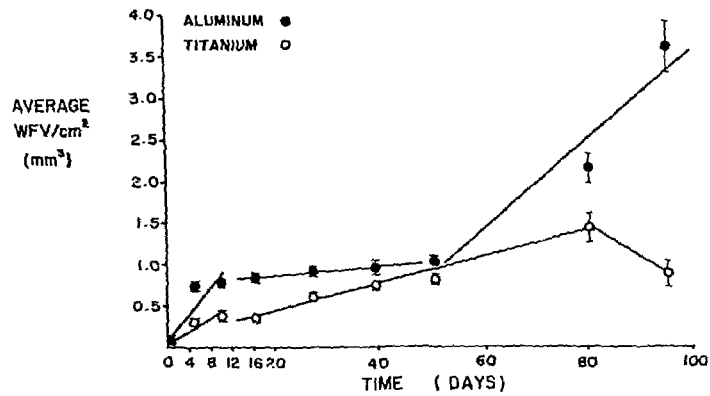


Fig. 2

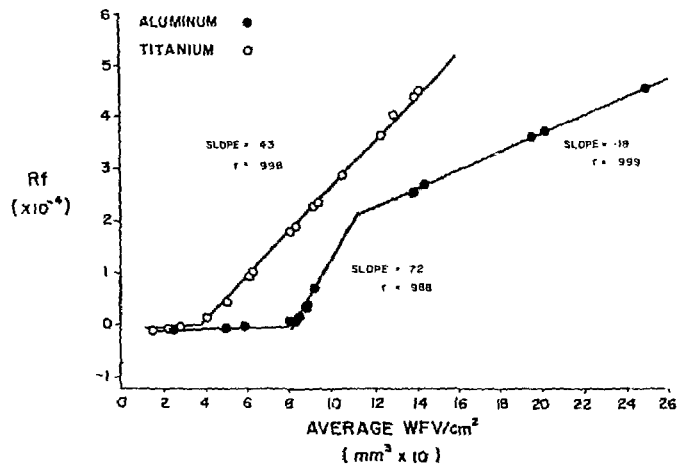


Fig. 3

RESULTS ON FOAM OTEC STUDIES AT
CARNEGIE-MELLON UNIVERSITY
AND
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The Foam OTEC¹ system was devised to eliminate expensive and vulnerable heat exchangers which are estimated to contribute over 1/3 the cost of a closed Rankine Cycle plant. It further replaces the huge low vapor density turbines characteristic of the usual open (Claude) cycles with standard hydroturbines. Briefly, a two phase (water-water vapor) system at surface temperature and pressure is expanded against a pressure of deep 5°C sea water. The expanding system is driven by the pressure gradient which is also coupled to a temperature and density gradient in the isentropic expansion. Available work is given by $C_p(T_2 - T_1 - T_1 \ln T_2/T_1) \approx \frac{C_p \Delta T^2}{2T}$. Available energy for a 20° AT is 2.9 J/gm of warm H₂O which can raise sea water about 600 ft.

The two phase tightly coupled vertical flow is maintained by using a foam. The water from the broken foam will turn the turbine. The foam requires a surfactant. For the system to be economically attractive the surfactant usage must drop to a few ppm. Foam flow has been modeled in a 4 inch i.d.

vertical pipe.

CMU PROGRESS F.Y. 79-80

In F.Y. 1979 it was found that wall friction effects pushed the expansion into the top of the column at higher flow rates.

In early F.Y. 1980 it was realized that the interaction of the wall friction and foam expansion is an extreme acceleration that tears apart the foam and causes high surfactant usage. This effect of wall friction would be negligible in the large diameter column anticipated for commercial use. In the laboratory this was mitigated by (1) reducing the length of the column, (2) limiting ΔT , (3) increasing the input water temperature to reduce the specific volume of the vapor.

CEER RESULTS

A program was set up in Puerto Rico to examine the problems involved in translating the low concentration surfactant solution to sea water. Data collected with a relatively long (30 ft) column indicates that there is very little difference between sea water and distilled or deionized water in so far as the measurement of the minimum surfactant needed to support foam flow.

Very preliminary results on a reduced (20 ft) column at CEER seems to confirm the above conjecture. The conclusion is that at the present stage of development, for "good"

surfactants, the flow dynamics rather than the chemical effects limits the surfactant concentration. Measurements made on several commercial mixtures of surfactants thus far indicate that the smaller molecules are more effective than large ones.

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SURFACE TREATMENTS FOR ENHANCEMENT OF
NUCLEATE BOILING HEAT TRANSFER

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EXTENDED ABSTRACT

Several alternate energy sources which depend on the transfer of large amounts of heat to a boiling liquid have been proposed in recent years. For most alternate energy schemes a large number of feasibility studies have been carried out and designs have been proposed; however, studies concerned with producing heat transfer surfaces which have very efficient heat transfer characteristics have been neglected. The effectiveness of any process which requires heat transfer to a boiling liquid can be greatly increased by using heat transfer surfaces which yield high heat transfer coefficients. That is, if the heat transfer can be enhanced the required heat exchanger surface can be reduced with a corresponding savings in capital expenditures.

A number of attempts have been made to enhance nucleate boiling heat transfer by surface modification. One of the earliest studies was performed by Jakob and Fritz [1]: they compared the nucleate boiling curves for a surface roughened by sand blasting and a surface that was fitted with a "roughness screen." The latter gave substantially better results than the sand blasted surface. The work of Jakob and Fritz was followed by a large number of papers describing studies on the effect that mechanical roughening and polishing had on heat transfer surfaces. These studies indicate that as surface roughness increases the nucleate boiling heat transfer coefficient increases.

In recent years a number of ingenious surface treatments which resulted in enhanced boiling have been described in the literature. Young and Hummel [2] determined the nucleate boiling curves for four stainless steel surfaces which had the following finishes: smooth, pitted, pitted with Teflon filling the pits and smooth with Teflon spots on the surface. The results of this study indicated that by providing poorly wetted sites on the surface, the average superheat of the surface could be reduced substantially for heat fluxes in the lower region of nucleate boiling; that is, the heat transfer coefficients were increased.

Almgren and Smith [3] treated a surface by flame spraying it with copper and zinc. The zinc was then etched away using hydrochloric acid. The resulting surface produced nucleate boiling of nitrogen at superheats of less than 1°R for fluxes around 10^4 Btu/hr-ft².

Carr [4] and Campbell and Rieger [5] reported that knurling heat transfer surfaces enhanced the nucleate boiling characteristics relative to unknurled surfaces.

Danilova et al [6] compared the nucleate boiling behavior of tubes coated by electrochemical deposition, spraying, and sintering. They found that the sintered and sprayed on coatings were the most effective surfaces.

Warner [7], Schade [8] and Vachon et al [9] reported that surfaces with ultra thin coatings of polymers yielded higher heat fluxes at a given temperature difference than uncoated surfaces did. In some cases the heat transfer rate was increased by a factor of five.

Union Carbide has developed and marketed a heat transfer tube [10,11] which is characterized by having a porous metallic matrix bonded to the boiling side of the tube. These tubes whose porous surface layer has a void fraction of 50 to 65% are reported to achieve nucleate boiling at extremely low temperature differences.

This paper briefly summarizes the above studies and other recent investigations which have produced surfaces that resulted in enhanced boiling heat transfer. The surface treatments and their applicability to various alternate energy schemes are discussed and areas of research which are needed to provide data for the evaluation of surface enhancement procedures are suggested.

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FLORIDA POWER CORPORATION
OTEC PLANNING STUDY

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ABSTRACT

In this paper, a planning study performed by Florida Power Corporation (FPC) for DOE to assess the impact of adding a 400 MW OTEC plant to the FPC system is discussed. The introduction describes the scope and purpose of the study, and is followed by a description of the FPC system and the base case expansion plan into which the OTEC plant was integrated. The reliability model and costs parameters for the OTEC plant are presented. Using the present worth of the total revenue requirements (PWTRR) as a composite measure of impact, the final section describes the technical and financial impact of the OTEC plant. Breakeven costs are determined and cable configurations are evaluated for a variety of conditions.

The study demonstrated that in terms of PWTRR, a 400 MW OTEC plant could become competitive for FPC if either its capital costs were reduced to \$1450/kw (See Figure 2) or if coal costs escalate at a rate in excess of 12% per year (See Figure 2). Further evaluation of the financial impact of OTEC using probabilistic production costing results to drive a corporate model showed, however, that for the assumptions made, the financing required to support the construction budget would be excessive. If ways around the financing problems can be uncovered or if the assumptions made drastically change, OTEC could become a viable option. Several cost saving steps were investigated including the removal of one of the three cables. However, due to the decreased reliability of the OTEC plant, the increased coal energy costs offset the savings in cable costs.

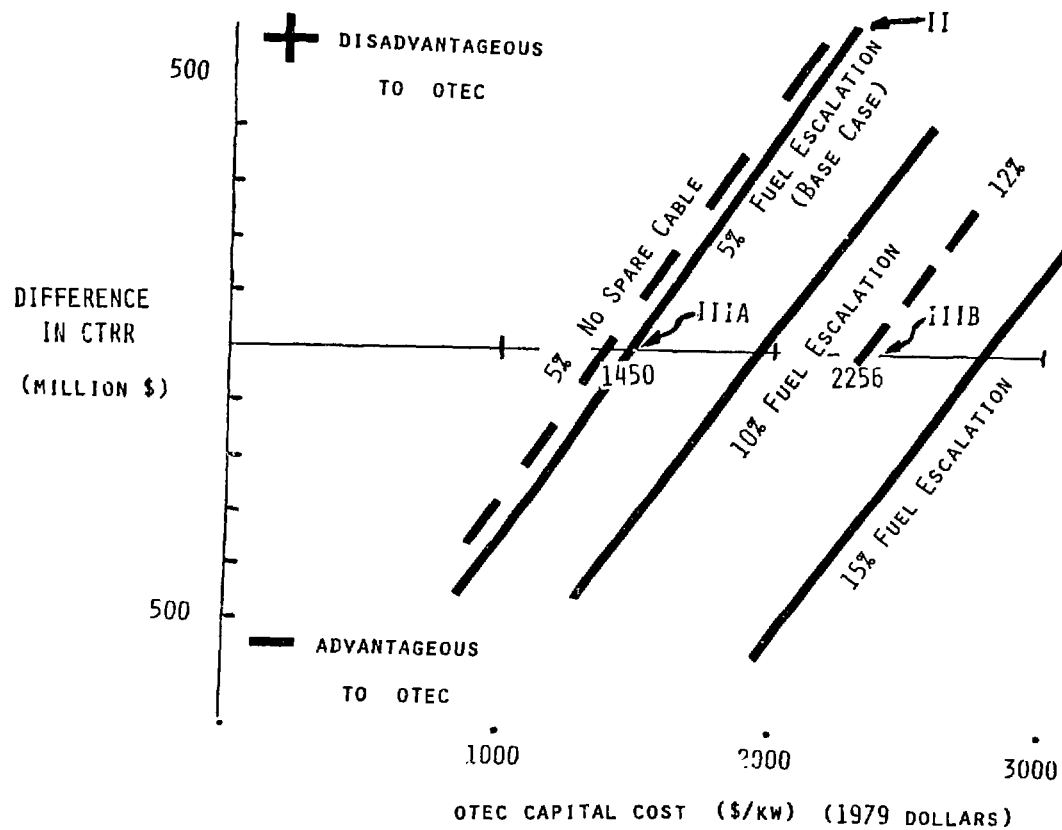


Figure 5-1

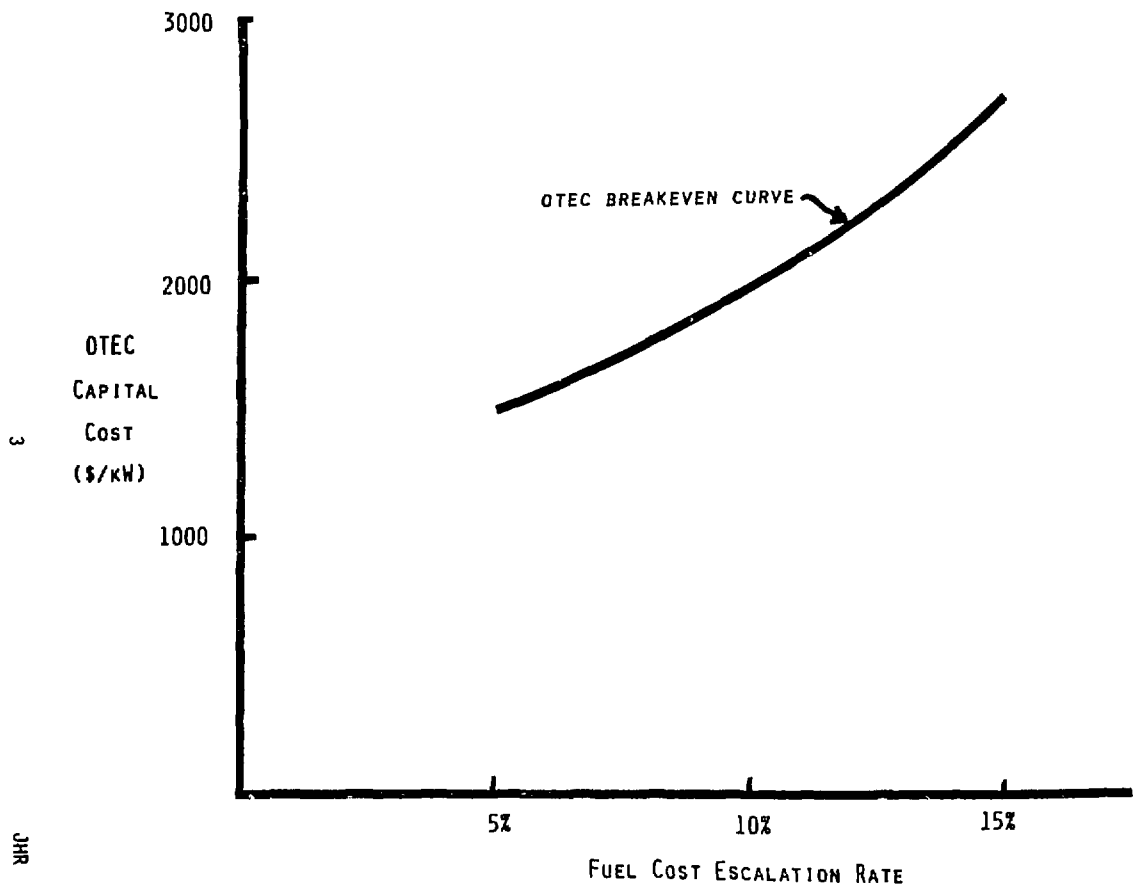


Figure 5-2

COLD LAKE: AN OVERVIEW OF A MEGA PROJECT

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On October 16, 1973, in a country that few people could place on a map, delegates from a small group of nonindustrial nations made an announcement that was to have a profound effect on world economics. That group was the Organization of Petroleum Exporting Countries, meeting in Kuwait. The announcement was of a dramatic increase in the price of their crude oil. And it signalled the end of one of the most exciting periods in history, one that witnessed unparalleled industrial development in widely dispersed areas of the globe. That development was largely supported by cheap oil. But, as the OPEC ministers insisted, development in the future would take place at much higher costs.

Since that time, oil supply has been discussed in terms of crises and shortages and some have even portended disaster for industrialized nations. All very gloomy words indeed. But while rising cartel prices and dwindling sources of conventional crude oil must not be treated lightly, it is time perhaps that a new word be introduced into the lexicon of the oil debate. Simply put, that word is opportunity -- an opportunity not only to aggressively pursue the development of an adequate supply but, just as importantly, to place a high priority on energy conservation. After all, the cheapest barrel of oil is the one that isn't used. In the last few years, some important contributions have been made to the energy supply in Canada and the United States through conservation. In Canada, for instance, the current average rate of energy consumption is growing by half of what it was in the late 1960s. If we had kept on using oil at the same rate of increase as we did prior to 1973, the demand today would be averaging more than 2.5 million barrels a day. Instead, it has levelled off at less than two million barrels a day. A significant savings on anyone's ledger sheet.

But conservation alone is not, as some have suggested, the universal promise for meeting our energy needs. To assure adequate supplies, we must explore all energy options, from traditional fuels such as coal and natural gas to more exotic forms of energy generated by the wind or tides or by the sun. In Canada, high-risk exploration for conventional oil in the past few years has brought some encouraging results from our eastern offshore and from the Beaufort Sea area in the Arctic. In Western Canada the quest for new supplies has brought about remarkable advancements in the production of nonconventional hydrocarbons from the country's vast oil-sands deposits. And, if oil-sands projects are allowed by government to proceed without undue delay, they will play a major role in Canada's long-term goal of energy self-sufficiency.

The oil sands that underlie northern Alberta are important because, simply put, they are reassuringly vast in their potential. They cover an area of about 17-million acres, roughly the size of Belgium and the Netherlands combined. The volume of bitumen in place in the four deposits of Cold Lake, Athabasca, Wabasca and Peace River are estimated at almost a trillion barrels. (In comparison, the estimated recoverable reserves of conventional crude oil remaining throughout the world total only 600 billion barrels.) However, less than ten percent of the oil in place can be recovered by conventional strip mining; the remainder is too deeply buried and too viscose to flow on its own. It requires the injection of steam directly into oil-sands deposits before it can be pumped to the surface.

Esso Resources Canada Limited is a pioneer in oil-sands research and development. The company is a major participant in Syncrude, the world's largest oil-sands mining project located in northern Alberta. Esso is currently sponsoring the first commercial in-situ oil-sands project near Cold Lake in northeastern Alberta. It is the culmination of almost 20 years of laboratory and field experiments, costing Esso and its parent company, Imperial Oil Limited, more than \$300 million to date.

If the Cold Lake project receives government approval, it will rank as a mega project in every sense of the term. It is the ultimate of thinking big. Cold Lake will cost an estimated \$9 billion (Canadian) to construct and will produce, upon completion, about 140,000 of light, sweet crude oil, equivalent to about 10 percent of total Canadian crude oil production at the beginning of this decade. About eight million man-hours will be required for the detailed engineering design of the project, and construction will require as many as 50 million man-hours. During the life of Cold Lake, about 8,000 wells will be drilled on the site.

The benefits to the Canadian economy, the rich opportunities for industrial growth, are obvious. The number of tradesmen, technologists, engineers, managers and clerical staff in Alberta at the peak of construction will be 10,000. A permanent operating staff of more than 2,000 will run the completed Cold Lake plant. Throughout Canada, the project will generate more than 6,500 jobs on increased staffs of suppliers of equipment and materials. And the plant itself will cover an area of five square miles.

The contribution of the project to Canada's economy and to its security of supply will be substantial. And, by reducing the country's dependency on foreign oil by about 50 million barrels a year, Canada's balance of payments will be improved by about \$1.5 billion a year in 1980 dollars.

The Cold Lake project, like other mega projects, has faced many challenges -- technical, environmental, social, economic and political. This paper will address some of the challenges encountered and overcome.

SYNCRUDE - OIL FROM ALBERTA'S TAR SANDS

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EXTENDED ABSTRACT

INTRODUCTION

Among the options available for future sources of energy is synthetic crude oil derived from bitumen contained in oil sands. Large deposits of such sands occur in Venezuela, Canada and the U.S.S.R., with smaller deposits known in other parts of the world. In Canada, experimental work on recovery is being carried out in several locations. Production of liquid hydrocarbons has been carried to commercial levels from the Athabasca oil sands. This paper will discuss one of these commercial plants, that of Syncrude Canada Ltd.

ALBERTA OIL SANDS

The total bitumen in place in the oil sands deposits of Alberta is almost one trillion barrels. Technology exists which permits recovery of shallow oil sands by mining. About ten percent of the Athabasca deposit is at these shallow depths. The two operating plants, of Suncor and Syncrude, employ open pit mining and hot water extraction to recover bitumen.

SYNCRUDE PLANT

The plant of Syncrude Canada Ltd. is located about twenty-five miles north of Fort McMurray, about two miles from the Athabasca River. The ore body being worked will permit production of about 130,000 B/D of synthetic crude over a period of twenty-five years. The total production from the one mine will be over one billion barrels. The plant produced its first oil in 1978, after a construction period of five years, and an expenditure (including a utilities plant) of about 2.5 billion dollars. The processing scheme includes open pit mining based on draglines, hot water extraction, fluid coking, and hydrotreating.

SOCIO ECONOMIC FACTORS

The construction of the Syncrude plant employed up to seven thousand people at the site, plus several thousand others throughout the country. The impact of the project was felt throughout the Canadian economy. About three thousand people are employed in operating the plant. This meant the expansion of a northern community from 9,000 to 25,000 people. The development of the infrastructure to serve this population growth took as long as the plant construction itself.

FUTURE SYNTHETIC CRUDE PROSPECTS IN CANADA

While production of syncrude from mineable oil sands has been brought to a commercial state, the other ninety percent of the reserves is the subject of intense activity. One commercial plant to recover deep bitumen in-situ is proposed for the Cold Lake area. Additional mining-based plants are also being developed. The future of these and other potential plants is dependent not only on adequate technology, but also on the tax and royalty regimes within which they would operate. In any case, if plants were built as fast as the Canadian economy could tolerate, their output would satisfy only a portion of Canada's liquid fuel requirements. Canada will have to continue to develop all its energy options if we are to achieve energy self-sufficiency.

ORINOCO OIL BELT

EVALUATION AND EXPLOITATION

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ABSTRACT

Due to the fact that oil is a natural nonrenewable resource and fundamental for the development of countries, and of very difficult substitution on the transportation and petrochemical aspects, the country possessing this great resource acquires a geo-political importance. This is the case of Venezuela with its Orinoco Oil Belt.

Heavy crudes, bitumen and bituminous sands have been historically margined in the oil market; but actually its economical feasibility is being considered due to the world energetic situation. Nevertheless, its development involves huge capital investments, execution time relatively long, necessity of additional recovery and upgrading techniques. Volumes of extraheavy crude will be produced in the next two decades to replace the production decline of medium and light crudes.

In Venezuela the heavy and extraheavy crude reserves constitute approximately half of the country's total reserves, and by multiple reasons, especially market reasons, its exploitation is being carried out at lower rates than those of medium and light crudes. Considering also the enormous accumulations of heavy crudes in the Orinoco Belt, it may be concluded that Venezuela will increase its importance as heavy crudes producer.

Petróleos de Venezuela started in 1979 an intensive research programme of methods and technologies of production, upgrading and processing of these crudes, as well as oriented exploration, to quantify by 1983 the hydrocarbon resources and determine the most attractive areas for exploitation. Even though the production cost of these crudes will be higher than those presently in exploitation, same will be lower than the development of other alternate sources such as the bituminous shales, carbon liquefaction, and other exotic energy generation methods.

Presently planning is being rushed for the first two projects with the purpose of producing 125,000 BPD of upgraded crude and 100,000 BPD of non-upgraded crude by 1988. Both projects will utilize proved technologies and companies of large experience for their design, construction and management.

Long-term plans indicate for the year 2000 a probable production potential of 1 MMBPD.

Although one of the projects includes upgrading, it is important to point out that the future exploitation of the Belt will require from the consuming countries the construction of refineries to upgrade and process these types of crude.

GUANIPA 100⁺
HEAVY OIL DEVELOPMENT PROJECT:
ORINOCO OIL BELT

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ABSTRACT

The purpose of this paper is to present an overall view of Meneven's heavy oil planning and development program within the Orinoco Oil Belt known as the Guanipa 100+ project.

The Orinoco Oil Belt is of special significance to Venezuela because of the vast reserves of heavy oil in the region and its commercial market value. Orderly exploration and exploitation of this area is being exercised in a prudent and rational manner since geological development, production extraction, field upgrading of heavy crudes, pipeline transport and refining of heavy oil are particularly cost-intensive, requiring a high degree of technical expertise in various disciplines.

Meneven is one of four operating subsidiary companies affiliated with the national oil company, Petróleos de Venezuela. Each of the operating companies, namely: Lagoven, Maraven, Corpoven and Meneven, have been assigned geographical areas of exploration responsibility in the oil belt. Partial exploitation responsibility however, has been assigned only to Lagoven and Meneven. The planning and development of the specific areas of the belt being managed by Lagoven and Meneven differ basically in the approaches to heavy oil extraction and oil gravity enhancement. In Lagoven's DSMA project field upgrading of heavy oil using refining processes is an integral part of this developmental strategy. Meneven's Guanipa 100+ project on the other hand relies heavily on utilization of light oil diluents produced from nearby fields to raise heavy oil gravities to marketable levels.

Meneven will develop that portion of the oil belt immediately south of its traditional area of operations in the state of Anzoátegui in Eastern Venezuela and the objective will be to generate 100,000 barrels of oil per day by year-end 1988. The accomplishment of this objective within the time designated requires extensive application of proven methods developed by Meneven in forty years of heavy oil exploitation and extensive technical support services from district field operations and local contractors. The magnitude of new heavy oil operations and optimization of older fields will be continually challenged by applying a variety of technical skills of both short and long duration. Technologies and operational skills will be provided from personnel resources within Meneven and professional expertise will be sought from outside sources, such as: Venezuelan engineering companies and research institutions and reputable international firms capable of supplying and transferring their technical knowledge and experience.

The Meneven planning and developmental program actually consists of two plans quite distinct, yet interrelated with one another. The first plan is an ongoing program of exploration drilling and short term planning with heavy reliance on Meneven's past experience in heavy oil operations. The second, partially overlaps the first, but is concerned with the attainment of medium and long range goals, and solution of problems caused by deficiencies in capacities of facilities, lack of trained technical personnel, impact of an enlarged oil operation on urban and agricultural communities, and commercial application of thermally-induced methods to increase oil recoveries and recoverable reserves.

D S M A

FIRST COMMERCIAL MODULE

ORINOCO OIL BELT

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The maintenance of Venezuela oil production in the proper levels to support the national development, is the prime responsibility of Petroleos de Venezuela, the holding company of the Venezuela oil industry. It became apparent that to be able to develop and maintain a production capacity of 2,0MMBD, is necessary to obtain the contribution of the heavy oil reserves of the Orinoco Oil Belt before the end of the century.

Lagoven operates in the vicinity of the Oil Belt many heavy oil fields, including reservoirs with gravities less than 10° API, from which are shipped approximately 100,000 B/D through two pipelines. The marketing blend is about 12° API as a result of mixing process with diluent and lighter oil.

South from the present Lagoven fields is the eastern sector of the Orinoco Oil Belt; sector which is known as Cerro Negro area and has oil sand thicknesses between 100-500'. Therefore, Petroleos de Venezuela assigned to Lagoven the task to plan the pilot commercial complex in the Oil Belt, with the first module to produce about 125,000 B/D of upgraded heavy oil, with the possibility of expansion to 500,000 B/D before year 2000.

The guidelines were to use only commercial proven technology and plan the module with complete installations for production, upgrading, transport and load in deep water port.

Also provisions have to be made for housing of all the employees necessary to run the module.

Lagoven started the preliminary stage late 1978. Both Lagoven and planning contractors experts determined the task necessary for planning of the project, called the study program. At that point also the official name was given to the project - DSMA, which means "Development of Southern Monagas and Anzoategui".

Lagoven team started the DSMA study program late 1979, and actually till september - the progress is about 40%. The planning stage has 140 major studies, with individual tasks requiring 1 million man-hours at a cost of about 72 MM \$.

The planning stage will be completed by late 1981, with the preparation of a budget quality estimate plus all other documents to be submitted for approval.

It became apparent that in order to complete the project before 1990 some execution activities should be started the planning phase is completed. For that reason Lagoven is in the process of selecting the prime contractor which will have the responsibility of general coordinations of the project. Lagoven established as mandatory the use of venezuelan companies in both in engineering construction, purchasing materials of equipment, wherever possible.

This project is a challenge to the venezuelan oil industry, since the size cost and unusual problems to be solved surpass several times all projects completed in the past.

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SESSION 2E

COAL TECHNOLOGY I (GASIFICATION)

COAL GASIFICATION IN THE UNITED STATES: PRESENT AND FUTURE

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EXTENDED ABSTRACT

Coal Gasification is an old technology dating back as early as 1620. In the United States a large industry was in place in the early 1900's based on gasification to produce fuel for industrial heating and for local distribution as town gas for household use. With the extension of natural gas pipelines into the northeast, the gasification industry came to a halt in the early 1950's. Existing gasifiers were scrapped and R&D activities halted except for small-scale activities in a few Government laboratories and universities.

The events surrounding the world oil supply in the 70's has produced a revitalization of interest in coal-derived fuels to replace imported oil. One of the key elements in the production of synthetic fuels is gasification. As shown in the accompanying figure, the production of low-sulfur fuel gas, liquid motor fuels, substitute natural gas, hydrogen, ammonia or chemicals from coal all involve a gasification step. For this reason the importance of gasification technology development is important in realizing the backout of imported oil which has been mandated by the President and Congress in the recently-passed synthetic fuels legislation.

The future commercial implementation of gasification technology will likely be impacted by the Feasibility Study, Cooperative Agreement and Loan Guarantee and Price Support funding which is being provided both by DOE and by the Synthetic Fuels Corporation (SFC). Those early activities will be concentrating on the use of foreign technology which has been commercially implemented in other countries. A second thrust will involve developing improvements in technologies to permit use of all U.S. coals. The DOE R&D program in gasification will provide information of use in these later phases of commercial deployment.

The technology for commercial production of many of the coal-derived products is available and is in place in South Africa, India, Germany and other countries of the world. The foreign technologies can be applied to some U.S. coals (primarily western) but not to all. The products in some cases do not directly match the required qualities for U.S. markets without significant expense in upgrading.

The current most significant impediment to deployment is the lost experience base for design, construction and operation on which rational funding and banking decisions can be made. The DOE demonstration projects are aimed at providing that experience in the U.S. marketplace of those near commercial

technologies. The other thrust is toward the development of improved processes to provide technology to handle the full range of U.S. coals in an environmentally acceptable manner, to make the proper suite of products for U.S. markets. The development timetable is predicated on the economics of synthetic fuels against the background of rising energy prices and within the strategic objective of displacing reliance on foreign energy sources. Recent analyses of energy supply and prices indicate that gasification can have market impacts as follows:

- Use of low-Btu gas for small, localized industries by 1983-85.
- Synthesis gas for fuel use for power generation and large industrial markets by 1985-90.
- Synthesis gas for production of methanol to gasoline by 1985-93.
- Synthesis natural gas by 2000 - 2010.

These impacts in the marketplace, which may be significantly accelerated through proper incentives, (assuming the completion of technology development) can provide a "backstop" for world oil prices as well as providing an alternate energy supply.

The Department of Energy program development approach to achieve these end goals will be reviewed. The timely development and demonstration of synthesis gas technology addresses the key identified barriers that would restrict commercialization. These include:

- Elimination of technical and cost uncertainties through the development of an experience base (product costs based on capital and operating costs).
- Confidence in operation of complex integrated processes.

The elements which build to these ends include:

- Advanced Research and Technology Development
- Equipment and Component Development
- Process Development and Integration
- Engineering Development and Scale-up
- Process Demonstration

In summary, the gasification program is constituted to provide the technology base upon which the commercial sector can build a synthetic fuels industry in the U.S. in a timely manner as markets become competitive.



ABSTRACT

UNIVERSITY OF MINNESOTA - DULUTH COAL GASIFICATION FACILITY

PLANT PERFORMANCE DURING INITIAL OPERATION

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Small scale gasifiers were extensively used in this country during the first half of this century. Most of these were operated on coke or anthracite coal. The majority were used in conjunction with coke ovens and water gas generators in town gas plants. The entire industry died with the introduction of inexpensive natural gas. Today, there are very few companies commercially using low-Btu gas produced from coal.

Several years ago DOE's predecessor, ERDA, initiated the Gasifiers in Industry Program to permit the construction of several small gasifiers to stimulate this state-of-the-art technology and permit an approach to reducing the consumption of natural gas.

The objectives of the program were:

1. Demonstrate low-Btu gasification through several applications in different operating environments.
2. Accumulate design, operating, environmental and cost data related to these specific applications.
3. Ultimately reduce the use of natural gas and/or oil through coal gasification.

During October 1976, the University of Minnesota and the Department of Energy entered into a Cooperative Agreement to install a ten-foot diameter, two-stage, Stoic gasifier at the Duluth campus of the University. The gasifier produces 60 million Btu/hour of low-Btu gas to provide boiler fuel to produce steam for campus heating.

The gasifier has recently become operational. During the startup, many problems related to design, component selection, installation and/or operation became apparent and presented problems requiring correction. The purpose of this paper is to cover those incidents and the corrective actions taken to resolve them. Specifically, it is hoped that the experiences gained at this facility can provide insight to others who might elect a similar approach to resolving their energy needs.

Sufficient experience has not been gained to date to provide realistic data related to economic, environmental and/or operational characteristics of the gasifier. However, the paper will address these elements in an effort to provide insight into these very important parameters.

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HEALTH AND ENVIRONMENTAL MONITORING AT THE UNIVERSITY OF
MINNESOTA-DULUTH COAL GASIFICATION FACILITY*

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ABSTRACT

The Life Sciences Synthetic Fuels Program at Oak Ridge National Laboratory was commissioned by the U.S. Department of Energy (DOE) to implement an extensive environmental monitoring and sampling program at the University of Minnesota-Duluth coal gasifier, part of the DOE Gasifiers in Industry program. One aspect of the monitoring program has involved the setting up of an on-line sampling and analysis system in the gasifier plant. This information provides supporting data to a more extensive laboratory analyses of process grab samples conducted at Oak Ridge National Laboratory (ORNL).

To date, a minicomputer system has been installed and programmed to continuously collect analog temperature, flow, and pressure data from plant instruments. A process gas chromatograph system, an SO₂/NO_x analyzer, and continuous CO monitors are also being used to collect

*Research sponsored by the Office of the Assistant Secretary for Environment, U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

process and work environment samples, and to record results on the computer. The computer software has been designed to ensure automatic data logging with a minimum of operator supervision, as well as providing data summary, data storage, and plotting routines. An on-site, bench-scale, gas chromatograph has been installed to provide complete analyses of all gaseous grab samples. Liquid and solid analyses are being performed at ORNL.

The collected data has been used to support the ORNL Health and Environmental Monitoring Program, including both industrial hygiene studies and site specific assessments to detail potential impacts on health and environment and the adequacy and efficiency of environmental and engineering controls. In addition, considerable, unforeseen, reliance has been placed on the installed monitoring capability by the gasifier plant operators. Preliminary information on the various process parameters of interest to the Health and Environmental Monitoring Program is presented.

INDUSTRIAL HYGIENE EXPERIENCE WITH LOW BTU COAL GASIFICATION

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Construction of a low-BTU coal gasification plant on the Duluth campus of the University of Minnesota has provided the proper setting for evaluation of health effects of coal gasification on employees working in that field. An extensive environmental and health monitoring program funded by the Department of Energy through Oak Ridge National Laboratory was begun 2-1/2 years ago, about six months prior to start-up of the gasifier. Experience to date indicates that coal gasification can be a comparatively safe and healthy industrial process, although the possibility of serious health effects will always exist.

The major potential occupational exposures have been found to be carbon monoxide, coal tar, coal dust, heat and noise. Of these, carbon monoxide presents the most serious acute exposure potential and coal tar, because of carcinogenicity, has the most serious chronic exposure potential.

Carbon monoxide is generated as one of the major fuels produced by gasification and makes up about 30% of the product gas stream. At that concentration, even a small leak can result in an overexposure and a large leak calls for immediate evacuation. Nevertheless, 8-hour or 24-hour average concentrations have rarely exceeded the standard of 50 ppm, and then only by a small amount. Personal, area and portable monitors for CO are all used daily to evaluate CO exposure.

Coal tar is also generated in the gasification process. Human exposure can result either from inhalation of aerosols or from skin contact with condensed tars. Aerosols are produced from leaking valves or flanges, but generally have been controlled. Limited data indicate that airborne coal tar levels range from .001 to .016 mg/m³ (cyclohexane-soluble fraction). Skin contact, which is most apt to occur during maintenance and clean-up procedures, is difficult to control because protective equipment must be used by the workers to avoid contact. A combination of education and monitoring has been adopted to ensure worker adherence to safe practice.

Coal dust exposure has been found to be excessive only during specific

handling operations. The problem can be ameliorated by increased local ventilation and equipment redesign to reduce the amount of coal handling.

Because the gasifier is enclosed within a building, heat stress can become a problem during the warm months. A few measurements at the hottest periods indicate that it is possible, although not too likely, to exceed the WBGT maximum of 32.2°C, especially during poking operations.

The gasifier is sufficiently noisy in several areas and during particular operations that hearing protection is mandatory. Coal feed valve cycling, manual poking and coal handling all initially resulted in noise levels near or over 100 dB(A), although mufflers on the coal feed valves have reduced that source by 25 dB(A). Background noise levels are approximately 85-90 dB(A).

A full medical monitoring program, including 12-lead EKG, lung function, chest x-ray, audiogram, and routine physical exam with blood tests, has been started for all gasifier employees.

NEW INSTRUMENTS FOR PLANT AREA AND PERSONNEL MONITORING*

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ABSTRACT

Original environmental and health planning documents for coal gasifiers in industry called for establishing the level and nature of exposure in the worker's environment. The selection of area and personnel monitors for aromatic pollutants associated with coal oil or coal tar separation operations was one of the major targets. Instruments that were then available to the industrial hygienist were inadequate for carrying out these tasks satisfactorily. Consequently, to fill this gap in our knowledge, a new generation of portable, rugged and reasonably inexpensive instruments is being developed. This presentation focuses on three new monitoring devices developed at Oak Ridge National Laboratory, each of which has been field tested in a low Btu coal gasification plant.

The first instrument is a derivative ultraviolet absorption spectrometer (DUVAS) designed primarily for real-time measurement of aromatic vapors such as benzene, phenol and naphthalene or its alkyl derivatives. This instrument is microcomputer controlled and has multipollutant monitoring capability with detection limits as low as a few ppb. An example is given of the successful use of the DUVAS to monitor aromatic vapors leaking from the knife valves below the feed lock hoppers of a gasifier.

The other two instruments measure oil or tar as surface contamination. Both instruments use ultraviolet light to excite fluorescence. A spill spotter is a general purpose instrument for use under a variety of lighting conditions. It produces 1 kHz modulated ultraviolet light that is directed through a dichromatic beam splitter that reflects the illuminating beam to a telephoto output lens. The modulated, longer wavelength returning fluorescence is collected by the telephoto lens, passes through the dichromatic splitter, and emission filters, and is detected by a photomultiplier tube. Measured surface fluorescence is read out as an audio signal whose frequency increases with the measured fluorescence intensity, and as a voltage on a digital meter. The spotter detects 0.1 μg of perylene at distances of up to 1 m, and has been used to monitor contamination cleanup at a gasifier.

The second surface contamination monitor is a lightpipe luminoscope. It is specifically designed to measure residual contamination on the skin. Low intensity, unmodulated ultraviolet excitation and fluorescent light are directed to and from the skin through a bifurcated fiber optics lightguide and stethoscopic head that is pressed against the skin. By using light excitation at 350 nm with a 50 nm bandwidth and a radiant flux only 1/100th that of sunlight, oils and tars can be detected at levels of a few nl or $\mu\text{g}/\text{cm}^2$.

*Research sponsored by the Office of Health and Environmental Research, U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

ABSTRACT

Source Test and Evaluation Program at
Glen Gery Coal Gasification Facility

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This paper presents the results of a Source Test and Evaluation Program conducted at a commercial coal gasification facility. The facility uses a Wellman-Calusha gasifier to produce low-Btu fuel gas from anthracite coal. The major objective of the test program was to perform an environmental assessment on the facility's waste streams and fugitive emissions. Results from the chemical analyses of the plant's waste streams indicated that all waste streams contain organic and/or inorganic components which may have potentially harmful health and/or ecological effects. In the pokehole and coal hopper gaseous emissions, CO, NH₃ and possibly Fe(CO)₅ were found to be of major concern. The gasifier ash and cyclone dust contained a number of trace elements and possibly organics that may be potentially harmful. Analyses performed on the leachate from these two solid waste streams indicated the leachate may have potentially harmful health and/or ecological effects; however, all but one element (Pb in the cyclone dust leachate) were below RCRA Guidelines.

Overall, the indicated potential health and ecological effects of the Wellman-Calusha facility's waste streams were found to be significantly lower than those for waste streams produced by gasifying bituminous coal. This was due principally to the much lower levels of organics in the Wellman-Calusha facility's waste streams. The results of bioassay screening tests also indicated lower potential effects of the facility's waste streams.

As part of the test program, on-line instrumentation to monitor gaseous species (H₂S, COS, CS₂, SO₂, NH₃, and C₁ - C₄⁺ hydrocarbons) was developed. The results from the on-line instrumentation were validated by alternate sampling and analysis techniques.

EXERGETIC ANALYSIS OF COAL GASIFICATION PROCESSES

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EXTENDED ABSTRACT

The concepts of availability, exergy, and exergetic efficiency are developed for use in evaluating coal gasification processes. Thermodynamic surroundings are selected using the approach of Bosnjakovic [1,2], resulting in process dependent surroundings containing H_2O , CO_2 , O_2 , and N_2 .

The basis for the exergetic (availability) approach to thermodynamic plant analysis is that each form of energy (work, heat, enthalpy) contains two parts: a useful part called exergy, which can be converted into any other form of energy; and a ballast part, called unergy, which is not useful. The exergy of each form of energy is derived as well as the equation for the exergetic efficiency.

The use of the analysis is demonstrated by applying it to the Synthane Gasification process using a Pittsburgh Seam feed coal. The process was simulated using the computer program BILANZ [3]. Values of the thermodynamic properties (enthalpy and entropy) of coal, char, tar, and ash were calculated as a function of temperature and material composition using the approach of Eisermann [4].

Results of the exergetic analysis include an overall exergetic efficiency of 61.2% using the plant design presented by Farney [5] and Pittsburgh Seam feed coal. Increasing the ratio of steam to oxygen fed to the gasifier from 6.83 to 10.0 was found to increase the overall exergetic efficiency to 64.6%. Utilizing an alternate methanator design similar to one presented in an IGT HYGAS process design [6] was found to increase the overall efficiency at the original steam to oxygen ratio of 6.83 to 62.3%.

The production cost of the substitute natural gas (SNG) product from the Synthane process was found to be \$4.61/GJ in third quarter 1979 dollars. The SNG production cost was found to decrease from \$4.61/GJ to \$4.37/GJ when the ratio of steam to oxygen fed to the gasifier was increased from 6.83 to 10.0. A 50% increase in coal cost was found to increase the SNG production cost by 15%, while a 100% increase in coal cost increased the production cost by 30%. Changing to the alternate (HYGAS) methanator resulted in a decrease of \$0.21/GJ in SNG production cost.

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HRI's Gasification Program

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HRI has been involved in the development of various gasification technologies since the middle 1940's. Early activities led to the partial oxidation process to produce a hydrogen-carbon monoxide synthesis gas mixture from heavy liquid hydrocarbon feedstocks. This process has been commercially applied by others and is now being extended to handle solid hydrocarbon feeds.

HRI's continuing gasification program has concentrated on fluid bed systems. Anthracite silt was gasified in the presence of steam and oxygen in a 26.5 inch inside diameter fluid bed reactor. The unit was later used to evaluate the gasification of pretreated bituminous coal.

Under U.S. Department of Energy funding, the concept of fast fluidization of coal is being evaluated. A unit has been constructed at HRI's R&D Center to process up to ten tons of feed per day. Anthracite has been gasified successfully and initial operation on untreated bituminous coal has been demonstrated. Additional testing on bituminous coal is expected to be carried out during the fourth quarter of 1980.

Fluid bed gasification has been successfully applied to the conversion of heavy oils into fuel gas and light liquid products in the Dynacracking Process. A commercialization program is currently in progress that will lead to the commercial-scale demonstration of this technology.

The application of fluid bed reactor systems to other areas of hydrocarbon chemistry will also be discussed.

COAL AND WOOD GASIFICATION - TECHNICAL AND ECONOMIC PERSPECTIVES

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EXTENDED ABSTRACT

The use of coal and wood as alternative energy feedstocks is gaining rapid interests among various industrial sectors. A number of conversion technologies are either commercially available or under various stages of development to convert coal and wood to gas, liquid or solid fuels. The conversion processes include thermochemical (gasification, combustion, pyrolysis, liquefaction, indirect liquefaction) and bioconversion (fermentation and anaerobic digestion) technologies. Among these processes, the gasification of coal and wood to produce low-Btu gas for use as a retrofit fuel to oil and gas fired boilers and furnaces is one of the most promising near-term technologies, and Gilbert has been involved in this area for many years for a number of industrial clients.

The paper is concerned with technical and economic comparison of gasification of coal vs wood to produce low-Btu gas for application to existing boilers and kilns. The characteristics of both as-received and prepared coal and wood were first compared to determine its advantages and disadvantages as gasification feedstocks. Then, a baseline plant capacity of 6×10^9 Btu/day was selected to perform conceptual design and economics for the following five cases of producing low-Btu gas from these feedstocks: [1,2,3,4,5,6]

- o Hot raw gas from wood.
- o Cold, clean gas from wood.
- o Hot raw gas from low sulfur coal.
- o Cold, clean gas from low sulfur coal.
- o Cold, clean desulfurized gas from high sulfur coal.

For the gasification of coal, commercially available stirred-fixed bed gasifier was selected whereas either downdraft or updraft fixed bed was selected for the wood gasification. For the case of cold, clean desulfurized gas, the Stretford plant was selected for the desulfurization.

The economics of these five cases were compared to make relative assessment of the costs of producing low-Btu gas, as shown in Table 1. The gas distribution and retrofit considerations will also be included in the discussion. Conclusions are drawn from the study for the technoeconomic perspectives of coal or wood gasification, including further study requirements to select one feedstock over the other based on site-specific and end-use-specific applications. Gas cost sensitivity curves are also developed for varying wood and coal costs.

TABLE I
ECONOMICS OF COAL AND WOOD GASIFICATION
Basis: Mid-1980 Price
6 x 10⁹ Btu/day Low-Btu Gas Plant Capacity

Case No.	1	2	3	4	5
Feedstock	Wood	Low Sulfur Coal	Wood	Low Sulfur Coal	High Sulfur Coal
Product Gas Type	Hot Raw	Hot Raw	Cold, Clean	Cold, Clean	Cold, Clean Desulfurized
Total Plant Investment, MM\$	6.07	6.23	8.86	10.91	13.19
Annual Operating Cost, MM\$/Yr ^(a)	4.27	5.19	5.98	6.16	6.30
Gas Product Cost, \$/MM Btu	2.95	3.49	4.16	4.50	4.79

(a) Based on delivered feedstock costs of \$55/ton, \$45/ton and \$27/ton for low sulfur coal, high sulfur coal and wood respectively.

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COAL LIQUEFACTION STUDIES USING ZINC CHLORIDE
MELTS AND H-DONOR SOLVENTS UNDER MILD
TEMPERATURE AND PRESSURE CONDITIONS

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ABSTRACT

Though the United States has reduced its petroleum consumption as much as 1½ million barrels per day by conservation measures and cutting down the consumption of gasoline, the Nation cannot afford to slacken its drive to reduce its dependence on foreign oil. Emphasis in the national energy program on alternative energy sources and on the development of coal conversion processes to liquid fuels should continue.

In the present study, Zinc Chloride salt melts were employed as a homogeneous catalytic medium to hydrogenate samples of Solvent Refined Coals obtained from both the Wilsenville and the Tacoma plants, and also (Kentucky 12) bituminous coal samples. In some of the experimental runs, hydrogen donor solvents such as tetralin and hydroquinone were also used in conjunction with the salt melts.

Batch experiments were conducted in a bench scale pyrex stirred-tank reactor under low hydrogen partial pressures (1 atm.) and relatively low temperatures (in the range of 190-230 °C). Asphaltene and oil contents of the treated coal samples were obtained by means of Soxhlet extractions with hexane and toluene. Some of the extracts are being analyzed with a high pressure liquid chromatograph and the constituent compounds of these extracts are being identified by means of GC mass-spectrometry.

Preliminary results indicated that zinc chloride melt alone as solvent medium and catalyst has no value for further liquefaction of SRC under the present experimental conditions. Negative aspects of zinc chloride melts were eliminated by the addition of tetralin to the reaction mass. Under certain experimental conditions, though the total toluene solubles of the SRC were not significantly changed, oil fraction of the SRC has been increased considerably at the expense of asphaltenes. A considerable reduction of sulfur content was also obtained. In the case of bituminous coals (Kentucky 12), a combination of zinc chloride, tetralin, and hydroquinone together serving as reaction medium produced a product comparable to the Solvent Refined Coal which was a product of a high temperature, 800-870 °F and a high pressure (1000-3000 psi) process. In the present study, a massive chemical attack was mounted to achieve similar liquefaction results as obtained under massive temperature and pressure attack. If the unconverted chemicals could be recycled, there is no reason why a process based on the present approach cannot be economically viable.

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SESSION 3E

SYNTHETIC FUELS

A SURVEY OF SYNTHETIC FUELISHNESS

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EXTENDED ABSTRACT

Wood, coal, oil, natural gas, kerosene and other petroleum derivatives and nuclear fission reactor plants, through "burn-up" of nuclear fuels, have all been used to provide heat for direct use in homes, institutions and industry, and to generate mechanical and electrical power using the Otto, Diesel and Rankine heat cycles. These fuels are considered to be natural since they are found in nature and are used after varying degrees of processing, enrichment or refinement. Other energy sources include hydro power, wind power, geothermal heat and heat or electricity converted from solar energy captured in stationary flat plate, one-axis tracking linear-trough and two-axis tracking spherical, parabolic or heliostatic collectors. These sources of energy also exist in nature, but are not fuels since burn-up is not required. This leaves a host of fuels which can be synthesized from natural materials using an equal number of electrical or chemical processes. These synthetic or manufactured fuels include coal gas, fuel oils derived from coal, solid fuel residuals, methane derived from sewage or kelp, ethanol derived from fermentation of grains, methanol derived from destructive distillation of wood, and hydrogen derived from electrolytic dissociation of water, or from fossil fuels using chemical processes. Hydrogen, in turn, can be synthesized with nitrogen to form liquid ammonia (NH_3) or with carbon monoxide to form methanol (CH_3OH). Synthetic fuels are not new. Early examples of synthesized fuels include charcoal, coke, coal gas and pure hydrogen gas. Coal gas was piped for sale and was the major "illuminant" until replaced with natural gas piped thousands of miles from the oil fields. This demonstrates the real need for a commonly available fuel gas irrespective of its source.

A major use of synfuels was made by Germany in WWII. Four coal-to-liquid fuel plants were built prior to 1939 and these sustained the German planes, tanks and troop carriers until 1943. Reduced to unsuccessful infantry attacks at Stalingrad, just short of the Baku oil fields, the bubble burst and a long retreat to ultimate defeat was under way. As a part of U.S.A. war spoils, we brought back numerous German V-1 and V-2 rocket engineers, the aniline dye process which is a coal derivative, and the guts of their coal-to-liquid fuel program. Here synfuelishness began. It was already known that the then existent US oil reserves would be exhausted by 1970, and a program to duplicate the German coal-to-liquid fuel plants was initiated and then dropped. Reasons included the tremendous proven oil reserves of Araby at less than \$2 per barrel, assumed certainty of fission reactor power to do everything else, and progressive discoveries of new oil fields. Now we know that oil can be priced above \$30 per barrel and that the new reserves as in Alberta, Alaska, the North Sea and Yucatan will merely prolong the problem. In America, we are asked to expend 140 Billion USD to reinvent the wheel. The conversion of coal to liquid fuel requires up to 2# of coal to yield 1# of oil or gas fuel. In addition, expensive process plants are required. When

petrofuels are increased in price, it is not long after when the price of coal and nuclear fuels is raised to the same extent. It is clear that coal-based synfuels will always cost much more than vanishing fossil fuels, including coal. The proposed 140 billion USD program raises some very hard questions:

- (1) What is to prevent OPEC from lowering oil prices after the first syn-fuel plants go into production?
- (2) How is the sale of synfuels to the public to be enforced if other, less costly, fuels become available?
- (3) If the synfuel industry becomes unprofitable, will investors be left hanging and employees laid off, or will taxpayers be forced to subsidize still another ineffective nationwide activity?
- (4) Since fossil fuels are consumed twice as fast to create synfuels than if used directly, how can a nationwide program be justified in the light of equal national emphasis on energy conservation?

Synfuels have their place and a more modest program can easily be justified in line with the following points:

- (1) Prayerfully, nuclear war will never happen, but "conventional wars" seem to go on forever. Our armed forces cannot remain strong if most of our mobile equipment is dependent on foreign petrofuels which can easily be cut off. In the interests of survival over a non-nuclear long haul, the USDOD must have firm, local sources of synfuels.
- (2) The policies for insuring such firm, local sources of synfuels can be established by executive order by our President as Commander-in-Chief of our armed forces.
- (3) These policies will be backed by appropriations because a majority of our Legislators will be in favor of such a logical program intended to insure that we remain strong and free for the foreseeable future.
- (4) The armed forces synfuel procurements should be arranged to create a steady market for the synfuel industry. These procurements can also be used to encourage the continuous seeking of higher yields of synfuels per pound of coal.
- (5) The synfuel industry should be free to expand capacity above and beyond the needs of the armed forces, at its own expense, for sale of synfuels to citizens whenever this may prove profitable.
- (6) The synfuel industry should guarantee to meet the stated needs of the USDOD at a reasonable supply rate as to preclude excessive stockpiling. The USDOD should pay enough for synfuels as to permit an attractive return on plant investment.
- (7) The conversion of only the USDOD requirements to synfuels will permit the USDOE much greater latitude in searching for alternate energy sources having replenishable energies for general use both in the U.S.A. and abroad.
- (8) Such alternate energy sources are a must over the long haul which is the central theme of an earlier publication 17.

Synfuelishness has more comical aspects than the foregoing which dealt with wars, the necessary chemical processes to permit wars and the easy forgetfulness in semi-peaceful times when a useful technology can be set aside and forgotten. Here I refer to gasohol. Alcohols have been used to drive torpedoes in wartime and the highest priced racing cars in times of relative peace. Gasoline might have been used in the absence of alcohols, but

never gasohol. Gasohol is the generic name for a mixture of 10-15% of ethanol or methanol with 85 to 90% of gasoline. It has been briefly tried in numerous places in cars and trucks. On the whole, gasohol introduces more problems than it solves. Carburetors can easily be designed to fire in admixed air either ethanol, methanol, hydrogen or any other liquid or gaseous fuel. Any of these individual fuels fired from the proper carburetor or air admixer ratio will work all right in any existing automotive system. In general, vehicles firing alcoholic fuels instead of gasoline must have alcohol resistant gaskets and twice larger fuel tanks because the specific heat content of alcohols is less by the same ratio. In all other respects true alcohols appear to be superior to gasoline as a fuel for our cars, trucks and busses and other power drives using volatile fuel. The main superiority is that each growing season replenishes liquid or gaseous fuels derived from growing things in the field or kelp from the sea. Secondly, emissions are much cleaner.

Methane, or marsh gas, is generated by the decay of organic substances and is a principal component of natural gas. When all of God's creatures, large and small, pass gas, this gas contains methane and is highly flammable. Methane has been extracted from sewage and can be extracted from kelp. Kelp beds can be inhabited by seals, birds and fish and form microecological enclaves wherever such beds can be induced to grow. There is no fuelishness here because the technology exists. In addition, kelp can be converted in part to food and could help vanquish hunger, another ancient enemy of man. Needless to say, there has been little backing to date available to the pioneers in Kelp technology, but its future is necessarily bright /1/.

Alternate energy sources are often variable sources. Witness the wide variation in wind velocity, solar insolation, tidal eage velocity, and water current velocity of many rivers. For such sources, energy storage is a must if these are to be used as firm sources of power. Let us discuss solar-electric plants since insolation is at best a less than 50% proposition. At MICAES I and MICAES II, papers were presented which described such firm power solar-electricity plants /2/ /3/. These were referred to as dual purpose plants, since the output would be electricity, hydrogen gas and oxygen gas. The latter two items would be stored for later recombination in fuel cells having no fuel preparation section, boilerless steam turbines and compressorless gas turbines. Fuel cells, if operated at 68 atma pressure and 811°K, could have exhaust steam passed through AIEEE/ASME preferred standard units to obtain the highest thermal efficiencies attainable in the absence of 80% efficient fuel cells /4/. Above 80% fuel cell efficiency, or in very small units, the need for backup steam turbines ceases to exist. During normal sunny days, sodium-potassium liquid metal eutectic alloy coolant would be recirculated to remove heat from solar energy collectors with weightless balloons having sun tracking means /5/. The coolant would bring condensate heated from the AIEEE/ASME preferred standard temperature to the boiling point, boil the feedwater, superheat the steam and reheat the steam in low cost stainless platefin type heat exchangers in order to drive modern high efficiency steam turbine generator units. As these large plants are built further from the USA sun belt, they become larger and generate more

hydrogen and oxygen. This is of interest, since heating gas is of least interest at the Yuma, Arizona capital of the Sun Belt, and of most interest in winter in places like Minneapolis-St. Paul and Boston. Generation of hydrogen for such plants requires low cost rectifiers and electrolyzers /6/.

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WATER AND ENERGY USAGE IN SYNFUEL PRODUCTION

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Abstract

The water and energy requirements for the production of synthetic gas/liquid fuels have been analyzed. A detailed plant-level evaluation of the rates of process and cooling water consumptions has been performed for major synfuel processes, including coal gasification, coal liquefaction, oil shale retorting (surface and modified in-situ) and ethanol production from biomass. The ranges of net energy consumptions and thermal efficiencies have been established for these synfuel processes. In addition, theoretical bases are developed to determine the limits of energy and water requirements for synfuels production. The effectiveness of both energy and water usage is evaluated in terms of variations in feedstocks, products and processes.

THE ICELANDIC OPTION: HYDROELECTRICITY,
GEOTHERMAL HEAT, AND PEAT FOR SYN FUEL PRODUCTION

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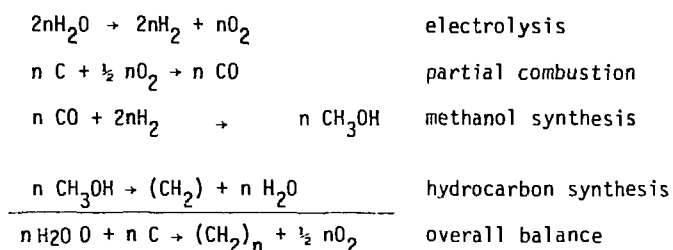
ABSTRACT

Iceland (population 220,000) uses about 500 MW of hydroelectric power and 500 MW of geothermal power (mostly for space heating) and imports 630,000 tons of refined oil products per year. The rate of oil consumption corresponds to about 1000 MW(th), giving a total energy consumption rate of about 2000 MW. With at least 2500 MWe of unharnessed hydropotential and possibly more than 7500 MWth of unharnessed geothermal, the country could, in theory, become totally energy independent. The problem is to convert these energy sources into transportable fuel, especially for the fishing fleet. (Cars can be electrically driven; fishing vessels not economically so.) Whereas Iceland has no coal or oil, but does have peat; the latter may provide carbon feed stock for synfuel manufacture.

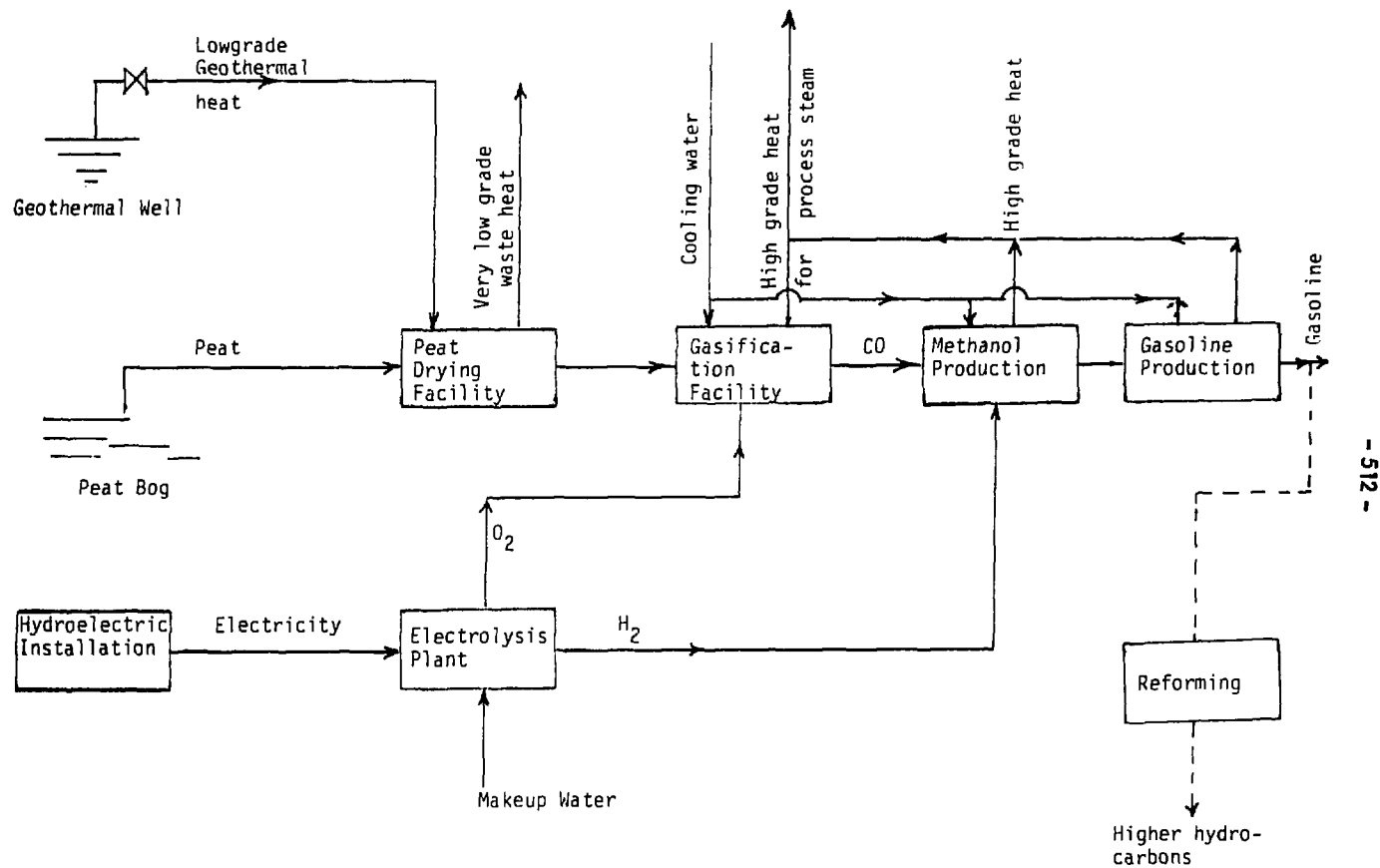
Peat has such a high moisture content that its energy of combustion hardly suffices to dry it. As solar drying is only possible on an intermittent basis in Iceland, a combination of mechanical and geothermal drying appears the most feasible method. As geothermal heat is essentially low grade heat (less than 250°C), peat drying provides a good use for it. In return, one acquires full utilization of the heat of combustion of the peat which can provide high grade heat for other processes.

The peat can then be gasified, for example in an IGT* type of gasifier, with supplementary hydrogen produced by electrolysis, thus providing feed stock for a Fischer-Tropsch type of fuel synthesis. Alternately, it can be partially combusted to CO, catalytically combined with electrolytically produced hydrogen to form methanol which, in turn, can be converted to hydro-

carbon fuel by the Mobil process. This sequence will be:



The government has instituted a synthetic fuels committee to study feasible processes. A preliminary study of the economics of a synfuel manufacturing system such as that outlined in Figure 1 has been undertaken. Such a facility would produce 110,000 tons of hydrocarbon fuel annually, would use 3400 tons/day of wet peat, 1200 tons/hour of air heated with 85°C geothermal water fed at a rate of 100 l/sec. A 250 MW hydroelectric installation would be required to furnish power for electrolytic production of 14,300 tons annually of hydrogen. Preliminary studies indicate that at 15 mils/kwhr electric power cost (the cost of the geothermal heat is much less significant) and 20% fixed charges, gasoline could probably be manufactured for about \$64/bbl.



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Figure 1. Flow Sheet of Contemplated Process

SUBSTITUTE NATURAL GAS AS AN AUTOMOTIVE FUEL

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ABSTRACT

Our major resource by far is coal. The objective of this study was to evaluate the potential of substitute natural gas which can be derived from coal as an automotive fuel.

In this study, a single cylinder engine was used to obtain basic engineering data on the relationship between exhaust emissions and air fuel ratio and to compare emissions from substitute natural gas with those from gasoline. In addition, a high production automotive engine was used to study the relationship between emissions, air fuel ratio and ignition timing using substitute natural gas.

Results showed that the light-load, lean-limit misfire region of substitute natural gas begins at an air-fuel ratio between 130-145 % of stoichiometric. Changes in ignition timing significantly influenced emissions of nitrogen oxide and hydrocarbons but had little effect on carbon monoxide emission. Low emissions can be achieved (by adjustment) without heavy penalty to engine performance.

PROPERTIES OF METHANOL-AIR MIXTURES
AND PRODUCTS OF COMBUSTION

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INTRODUCTION

Methanol is currently of considerable interest for use in automobiles as an alternative to petroleum based fuels. The technology required for its utilization is very similar to that for gasoline so that storage facilities and handling procedures, as well as service station and vehicle hardware need suffer little change. Similarly its production from coal or renewable biomass is technically well developed so that in total, methanol is probably the most attractive alternative fuel economically and politically for the near future. Even in a hydrogen economy, methanol may find a place because it stores more hydrogen per unit volume than liquid H_2 itself.

Charts or tables of the properties of fuel-air mixtures are commonly used in internal combustion engine and gas turbine cycle calculations in order to predict the performance of the devices. Starkman and co-workers [1] published such charts for methanol for a range of fuel-air equivalence ratios appropriate for spark ignition engines of the time; however, it has been shown recently [2] that the Starkman charts are in error in the lower temperature range because the methanol is not entirely vapourized as assumed in the calculations on which the charts were based. Furthermore, the temperature range covered by the charts is not sufficiently broad to include all the values of interest for cold weather starting and operation nor high performance applications with reduced manifold heating or fuel injection.

In this paper, calculations are presented for the determination of methanol-air mixtures covering a temperature range down to $-40^\circ C$ as well as for equivalent ratios much leaner than previously published charts which were not suitable for use in gas turbine cycle calculations.

CALCULATION METHODS

Properties of Gaseous Components In order to determine the properties of gaseous components, they were assumed to behave as ideal gases having temperature dependent specific heats of the following form:

$$C_p = a + bT + cT^{-1} + dT^{-\frac{1}{2}} + eT^{-2} + fT^2 \quad 1$$

where C_p = constant pressure specific heat, J/mol K

a b etc are coefficients characteristic of the particular gas concerned

T = absolute temperature, K

Enthalpy $\bar{h}$ of a particular gaseous component at a given temperature T above the reference temperature T^0 is then given by

$$\bar{h} = \int_{T^0}^T C_p dT \quad 2$$

Similarly entropy $\bar{s}$ above the datum conditions T^0 and P^0 is

$$\bar{s} = \int_{T^0}^T (C_p/T) dT - \bar{R} \ln (P/P^0) \quad 3$$

where $\bar{s}$ = molar specific entropy, J/mol K

$\bar{R}$ = universal gas constant, 8.314 J/mol K

Properties of Two-Phase Mixtures The change in enthalpy of a mixture of air, fuel vapour and liquid between two states 1 and 2 may be written

$$\begin{aligned} H_2 - H_1 = & n_a (\bar{h}_{a2} - \bar{h}_{a1}) + n_f [(\bar{h}_{g2} - \bar{h}_{g1}) + (VF_2 - VF_1) \bar{h}_{fg1} \\ & + (1 - VF_2) (\bar{h}_{fg1} - \bar{h}_{fg2})] \end{aligned} \quad 4$$

where n_a = number of moles of air

n_f = number of moles of fuel

$\bar{h}_g$ = enthalpy of fuel vapour, J/mol

$\bar{h}_{fg}$ = enthalpy of evaporation, J/mol

VF = vapour fraction = n_g/n_f

Similarly the change in entropy may be written

$$\begin{aligned} S_2 - S_1 = & n_a (\bar{s}_{a2} - \bar{s}_{a1}) + n_f [(\bar{s}_{g2} - \bar{s}_{g1}) + (VF_2 - VF_1) \bar{s}_{fg1} \\ & + (1 - VF_2) (\bar{s}_{fg1} - \bar{s}_{fg2})] \end{aligned} \quad 5$$

where the symbols are defined similarly to those of equation 4.

Assuming ideal gas behaviour and neglecting the small liquid volume, any vapour fractions less than 1 may be written (2)

$$VF = \frac{n_a P_f}{n_f (P - P_f)} \quad 6$$

where P_f = fuel vapour pressure

P = total pressure of the mixture

Vapour pressure of methanol was calculated using the Antoine equation (3)

$$\log_{10} P_f = A - B/(C + T) \quad 7$$

where the coefficients A, B and C used were those given by Wilhoit and Zwolinski [4].

Burned Gas Properties As well as the relations given above, the NASA Chemical Equilibrium Program [5] was used to determine burned gas composition.

RESULTS

In addition to tabular and graphical presentation of unburned methanol-air and burned gas properties, sample calculations are given to illustrate both the employment of the data in engine performance determination, and also the differences in performance resulting from the use of methanol rather than gasoline and kerosene in spark ignition engines and gas turbines.

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ON THE POSSIBILITY OF OBTAINING A CLEANER COMBUSTION BY ADDING
METHANOL TO FUEL OIL

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EXTENDED ABSTRACT

INTRODUCTION

Purpose of the paper is the analysis of the possibility of improving combustion of an heavy oil in an industrial burner by adding methanol. The main goal is to control if the air pollution can be more easily controlled by means of this technique, but also other problems are analysed, especially from the point of view of the configuration of the burner to be used.

The results obtained by means of the addition of water have been compared with those referred to methanol.

The percentage of methanol during the experiments was ranging from 0 to about 25% in weight.

EXPERIMENTAL APPARATUS

A burner with a max mass flow rate of about 40 kg/h has been used in the experiments; fig. 1 shows a scheme of the burner and of the oil and methanol feeding lines.

As it is possible to observe, each fuel is equipped with its separate feeding line; the mixing of methanol and fuel oil takes place in the mixer and in the injection pump, just before the head of the burner. Some problems have arisen during the running test due to the low boiling temperature of the methanol (64.4°C) and the necessity of preheating the heavy oil.

Methanol mass flow rate has been measured by a calibrated flowmeter, while heavy oil flow has been controlled by measuring the weight of the fuel in the tank.

Standard methods have been used to measure emissions and temperatures.

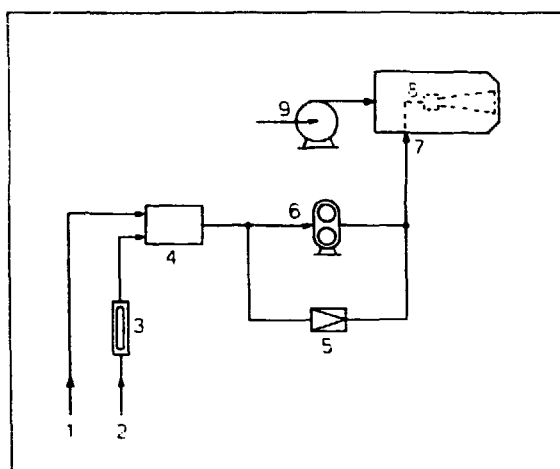


FIG. 1 - Scheme of the burner configuration with oil and methanol feeding lines.

1. Heavy oil; 2. Methanol; 3. Flowmeter; 4. Heavy oil - Methanol mixer; 5. Pressure gauge; 6. Oil-Methanol pump; 7. Burner; 8. Nozzle; 9. Fan.

EXPERIMENTAL RESULTS

Some representative experimental results are shortly considered in this section.

The main parameters here considered are

- carbon in the exhaust (as Bacharach number)
- pollutants in gas phase (HC, CO, NO_x)
- flame length.

Carbon in the exhaust. The influence of methanol is dependent on the excess air.

If the excess air is low an increasing of methanol leads to a rather strong decreasing in carbon emissions.

In the case of high excess air the influence of methanol is rather weak. Some representative results are shown in fig. 2.

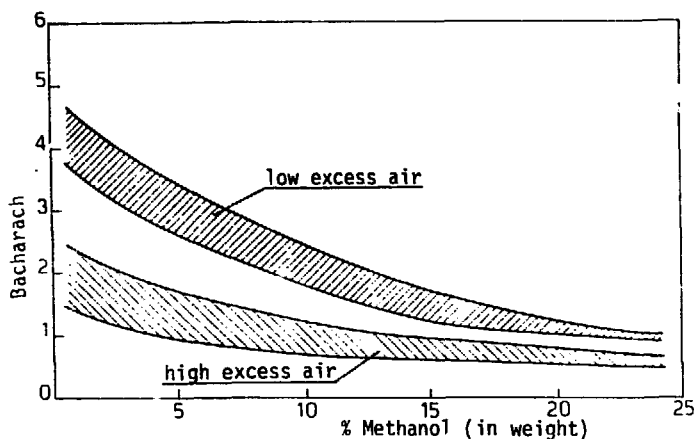


FIG. 2 - Carbon in the exhaust as a function of methanol concentration (excess air used as a parameter)

Unburned hydrocarbons. The unburned hydrocarbons in the exhaust are not strongly affected by methanol; it seems that they are mainly controlled by excess air and burner characteristics.

Carbon monoxide. The behaviour is similar to that of the hydrocarbons.

Nitrogen oxides (NO_x). NO_x concentration increases by increasing methanol percentage in the fuel. This can be due to an increased oxygen availability in the hightemperature region of the flame.

Flame length. The main effect of adding methanol seems to be a reduction of the length of the luminous part of the flame; this fact is probably connected with an easier evaporation of fuel droplets.

CONCLUSIONS

The main conclusion is that methanol can be profitably used in addition to an heavy fuel if the burner configuration is suitable.

An improvement of some characteristics of the exhaust gases can be observed, also if it is necessary to take into account a trend toward an NO_x increasing.

ON THE SUITABILITY OF ALTERNATE FUELS
FOR DUAL FUEL ENGINE OPERATION

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EXTENDED ABSTRACT

INTRODUCTION

Dual fuel operation provides the easiest way of substituting the diesel fuel by such alternate fuels as alcohols, biogases and hydrogen in compression ignition engines. In this method, the alternate fuel is inducted into the cylinder alongwith intake air and the combustion is initiated by injecting a small quantity of diesel fuel in the conventional manner. The extent of substitution and its effect on the engine performance depends on the nature of the alternate fuel. This investigation aims at getting a closer understanding of dual fuel operation so that alternate fuels can be effectively utilised in compression ignition engines for diesel fuel conservation.

EXPERIMENTAL WORK

A single cylinder, four stroke cycle, water cooled compression ignition engine developing 5 B.H.P. at 1500 R.P.M., the type of which is commonly used for irrigation purposes in developing countries, was chosen for investigation. A variable jet carburettor was attached to the intake manifold of the engine to introduce the auxiliary fuel. To get an insight into the manner in which the inducted fuel affects engine cycle parameters and performance, four pure hydrocarbon fuels of different molecular structure, namely n-hexane, cyclohexane, benzene and xylene and two commercial fuels, namely petrol and kerosine were carburetted into the intake air. The engine was operated at different load conditions covering the entire load range. At each load the inducted fuel proportion in the total fuel consumption was increased till unsteady operation due to knocking or missing and hunting was set in. Nitric oxide in the exhaust gas was measured by using a modified saltzman method. Exhaust hydrocarbons were measured by means of a flame ionization detector. Instantaneous cylinder pressure diagrams were recorded by means of water cooled piezoelectric pressure transducers fitted into the adaptors at the top of the cylinder head.

RESULTS AND DISCUSSION

The experimental work indicated that a wide range of fuels can be burned in diesel engines partly substituting the diesel fuel consumption. This can be done without any loss of thermal efficiency if the engine is operated at full load. Part load operation showed a decrease in thermal efficiency. With small proportion of auxiliary fuel, exhaust hydrocarbon concentrations were not affected appreciably at all loads. However, when large quantities of auxiliary fuel were carburated, they increased considerably.

The auxiliary fuel carburated into the intake air may undergo slow oxidation of the chain reaction type reducing the ignition delay of injected fuel and helping the combustion once the ignition sets in. Thus the effectiveness of carburation largely depends on the properties of auxiliary fuel such as volatility, enthalpy of vaporization, molecular structure, oxidation characteristics etc.

Knocking in dual fuel operation is controlled mainly by the ignition characteristics of auxiliary fuel. The maximum proportion of auxiliary fuel that can be carburated for smooth operation was observed to be a reflection of self ignition temperature and oxidation characteristics of the auxiliary fuel. For full load operation, 29.2 percent of total energy input could be supplied through benzene as auxiliary fuel; 28.7 percent through cyclohexane; 22.5 percent through xylene; 20.0 percent through petrol, 18.6 percent through kerosine and only 17.5 percent through n-hexane. As the load was decreased, with reduced cycle temperature level, large proportions of auxiliary fuels could be carburated operating the engine steadily.

The carburation of ring structure compounds used in the investigation did not appreciably affect the ignition delay of the injected fuel, though a slight decrease was observed with xylene. With increasing proportions, the maximum pressure increased slightly indicating that these fuels helped the combustion once the ignition has set in. When benzene and cyclohexane were carburated, their effect on various parameters was observed to be the same.

A reduction in exhaust temperature indicates the advancement of energy release in the cycle. When the fuels with good oxidation characteristics were carburated, the ignition delay of injected fuel reduced and the combustion proceeded at a faster rate thus reducing the exhaust temperature. When n-hexane, petrol and kerosine were carburated, a reduction in exhaust temperature was observed.

With increasing proportions of auxiliary fuel, carburation gradually decreased the part load efficiency of the engine. At part loads, the cycle temperatures are low which reduces the extent to which the slow oxidation of auxiliary fuel takes place. Also, as a smaller quantity of diesel fuel was injected under these conditions, probably an appreciable part of the auxiliary fuel either burns in the cycle or passes into the exhaust unburnt with consequent reduction in thermal efficiency.

ACKNOWLEDGEMENTS

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SOME ASPECTS ON USE OF KEROSENE AND PETROL BLENDS
IN SPARK-IGNITION ENGINE USING SURGE TECHNIQUE

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EXTENDED ABSTRACT

INTRODUCTION

Gasoline engines working on spark-ignition systems have been playing a very important role in modern civilization. Resources of petroleum products are being exhausted day by day and the shortage of conventional fuels is felt very much. There are only two alternatives to be adopted to overcome the present crisis of conventional fuels:

1. to increase the brake thermal efficiency and power output by increasing HUCR (highest useful compression ratio) for the given fuel or by modifying the design of engine.
 2. To find non-conventional substitute fuels or economical blends of conventional and non-conventional fuels.
- K.D.S.R.Somayajulu [1] carried out research work in the field of "Octane Improvement" from an engine point of view by using a surge cycle.

SURGE CYCLE WORKING PRINCIPLE

A surge chamber is connected to the engine cylinder. A surge chamber which is a closed chamber of a given volume is filled with air at a predetermined pressure and is separated from the cylinder by a flexible diaphragm.

Maximum cylinder pressure and the rate of pressure rise in the cylinder are dependent on the air pressure in the surge chamber. The surge chamber is very pressure sensitive.

When the pressure rise in the cylinder is high the surge chamber permits an increase in the cylinder clearance volume, resulting in a reduced rate of pressure rise. This results in a lower maximum cylinder pressure, smoother operation, better torque characteristics, better fast load performances, higher efficiency and higher brake mean effective pressure.. A surge cycle has a lower maximum pressure than the otto cycle but a greater one than that of a Diesel cycle. The cycle efficiency is between those of Otto and Diesel.

A surge cycle has the following advantages:

1. Low octane fuels can be used at normal compression ratios and better octane fuels at high compression ratios.
2. It is a very simple mechanism.

EXPERIMENTS

The author carried out the experimental work on a four stroke cycle Briggs and Stratton S.I. engine using five different blends of kerosene with petrol at compression ratios 5.3 and 7.47 to 1. For the given compression, while carrying out the experimental work with a surge chamber, suitable values of surge pressure, surge volume and the numbers of convolutions on the surge diaphragm were taken.

CONCLUSIONS

From the experimental result the following conclusions are drawn

1. At part-load and the lower compression ratio the brake thermal efficiency is improved with percentage increase of kerosene but at the higher compression ratio it is improved only upto 50% kerosene blend with petrol.
2. The knock-free maximum bhp is reduced with (a) the percentage increase of kerosene, (b) the increase of compression ratio.
3. Use of a surge chamber increases the knock-free maximum bhp, and reduces the brake thermal efficiency.

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SOME STUDIES ON THE PERFORMANCE AND NITROGEN-OXIDES
EMISSIONS USING GASOLINE-METHANOL BLENDS IN SI ENGINES

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EXTENDED ABSTRACT

INTRODUCTION

Due to rapid increase in the number of automobiles and the finite resources of petroleum crude oil, the world is facing the dual problem of energy crisis and air pollution. It is, therefore, essential that a sensible policy for the best utilization of energy sources available is adopted and, wherever possible, alternative fuels are used.

According to literature cited by Reed, et al.^[1,2] methanol stands out as the most desirable alternative, either as ^[3,4] pure or blended with gasoline since methanol is produced from the available vast coal resources at competitive prices and can be used in current automobile engines with some modifications.

The performance, pollution efflux and economy of an automobile engine are complex functions of the engine design, speed, spark timing, inlet manifold pressure, pollutant suppression on clean up systems and fuel. Of the many variables, engine compression ratio has a significant effect on fuel economy, but the compression ratio depends on the antiknock characteristic of the fuel. Methanol is known to increase the octane number of the gasoline and hence the engine can be operated at higher compression ratio. It has also been found that there is potential gain, both in fuel economy and pollution level, by operating the engine on very lean fuel mixtures. Lean combustion decreases peak flame temperature; when flame temperature decreases, it decreases heat losses,^[5] specific heat of combustion products and dissociation losses.^[5] However, due to decrease in flame speed, the mixture gives rise erratic combustion with the present gasoline. Methanol as a fuel when blended with gasoline has a good lean combustion characteristic due to high flame speed - about five times more than that of gasoline. Utilising Methanol blended with gasoline as an additive increases the octane number and thus can replace the additives, such as TEL or TML, eliminating thereby one of the dangerous pollutants.

The main object of the work reported here was to study

- (i) the effects of compression ratio, mixture strength on the performance of the engine with gasoline methanol blends; and
- (ii) the effects of air-fuel ratio, compression ratio on the pollutants of the engine with gasoline methanol blends.

EXPERIMENTS

Engine And The Associated System Tests were conducted on a single cylinder, four stroke, air cooled Briggs and Stratton engine of bore 7.62 cm and stroke 8.35 cm, and the spark timing was 30° bte. The engine was coupled to the alternator, with suitable loading devices. By increasing the resistances in the alternator circuit the speed of the engine could be changed.

The fuel was supplied to the engine by gravity through a metering system. The engine took air directly through atmosphere through a surge tank. A single column manometer was used to measure the pressure difference across the orifice plate.

The exhaust system was modified for the collection of exhaust gas sample and the gas was collected directly into the collecting bottles by the displacement of mercury.

Saltzman's absorbing reagent was used to determine the amount of oxides of nitrogen present in the exhaust gas. The colourless Saltzman's reagent turned to red violet when exposed to NO_2 . The oxides of Nitrogen present in the exhaust gas were directly proportional to the colour intensity of the reagent or absorbance. The absorbance of the solution was measured with the help of spectro-photometer.

CONCLUSIONS

From the experimental results the following conclusions were drawn.

1. Addition of Methanol helped in reduction of exhaust gas temperature.
2. Addition of Methanol reduced the NO_x emission upto 40 percent compared with the base gasoline. The maximum of 40 percent was obtained with 20 percent methanol blend at bsfc value of 21 percent higher, corresponding to the minimum bsfc without blends.
3. Addition of methanol increased thermal efficiency with slightly increased bsfc.

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REMARKS ON THE USE OF SYNTHETIC FUELS IN SERIAL AUTOMOTIVE DIESEL
ENGINES: INFLUENCE ON THEIR PERFORMANCES AND THEIR CONTRIBUTION
TO AIR POLLUTION

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EXTENDED ABSTRACT

The use of synthetic fuels in internal combustion engines and their possible environmental pollution is being under study for some time in the Istituto di Macchine e Tecnologie Meccaniche of the University of Trieste. This paper presents the main results of an experimental research which is part of a program, sponsored by C.N.R. (National Council of Research), on the use of alcohols and in particular methanol, as integrative fuels of gas-oil for 4 stroke Diesel engines.

A comparison has been made between performances and contribution to air pollution of a typical high displacement engine for medium and heavy truck, operating with binary gas-oil/methanol and gas-oil/ethanol mixtures, in different ratios, both in the supercharged and in the aspirated type. More over tests have been made on ternary mixtures obtained by adding variable quantities of additive to improve combustion conditions; for this purpose isopropilnitrate has been used. The engine was mechanically supercharged by helicoidal lobes volumetric compressor, and presently tests of comparison are in progress on the same type of engine but turbo-supercharged.

Inflammability characteristics of pure or mixed methanol at variable quantities of additive have been preliminarily studied on a C.F.R. test engine; while methanol influence on performances has been, in the first stage, studied on a single-cylinder engine for agricultural purpose. The results obtained have been widely confirmed by the tests carried out on multi-cylinder engine for medium and heavy truck.

By using methanol, decreases in power and increases in specific consumption are in line with the reduction in the heat value of the fuel mixture; such variations are more remarkable at higher r.p.m. and, in any case, in aspirated engine than in the supercharged type. In particular the increase in specific consumption is almost proportional to the rise in load at constant r.p.m. and for each percentage of methanol. By increasing methanol content in the mixture, variations in CO and HC emissions are practically negligible and also the increase in the grade of smoke is modest. On the other hand it is remarkable the reduction in nitrogen oxides, due to the cooling caused by high vaporization heat of methanol mixtures. At full load NO_x value decreases with the increase of r.p.m. for each type of mixture, while supercharging brings about an increase in NO_x emissions only around the speed of maximum engine torque; by increasing load NO_x emissions increase remarkably and with mean values undoubtedly higher in the supercharged engine.

During the tests, the engine regulations have not been changed: in particular the advance of injection has been kept constant in order to point out the different response and therefore the adaptability of a serial engine to fuel variations.

Tests with ethanol have shown its superiority towards methanol while nitrogen oxides emissions have been practically unchanged; their increase, in the supercharged engine, rises when speed decreases and it is minimum at maximum power speed.

The addition of an additive improves combustion conditions since it acts as a catalyst of oxidation reactions: hence the grade of smoke decreases. As far as performances are concerned, the addition of the additive is advantageous only for limited contents and for not too high methanol percentages: in fact with high quantities of methanol the cooling of the mixture may neutralize the improvement of its inflammability, shown by the increase in the cetane number. It can therefore result a total increase in the ignition delay which together with the lower heat value of the mixture, caused by the presence of the additive, brings about a reduction in the developed power. Such reduction, with a methanol content of about 30 % is almost equal to the quantity of additive added; while with 20 % of methanol the reduction in power starts from 2 % of additive after a short initial increase. Similar reasons explain the reduction of NO_x emissions. Therefore it

can be said that with mixtures with high content of methanol the only effect of the additive is similar to that of an inert diluent.

Finally, tests at partial loads have shown little influence of methanol content on efficiency and consumption which range between acceptable values only within full load conditions. The relative consumptions, on the other hand, increase as load rises at high r.p.m., while they are not affected by load at lower r.p.m. Even the NO_x emissions increase as load rises and that is more remarkable in the aspirated engine than in the supercharged type.

**THE EFFECT OF PRE-HEATING THE MIXTURE ON THE OPERATION
OF A BIFUEL MULTI-CYLINDER AUTOMOTIVE DIESEL ENGINE**

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EXTENDED ABSTRACT

INTRODUCTION

The ever increasing and insatiable demands on petroleum and its products by both developing and developed countries has resulted in an unprecedented raise in the price of crude oil. It has become imperative, for developing countries, to take steps to find alternate source of fuels for combustion engines used widely in the transportation sector. Among the many alternatives, it is believed that ethanol has many desirable characteristics as a diesel extender. The details of tests carried out on a six cylinder automotive diesel engine with hydrated ethanol as a bi-fuel are presented and discussed.

EXPERIMENTAL SET UP

A 6528 CC six cylinder automotive C.I. engine was used in the present work. A carburettor with a variable jet fixed to a modified induction manifold enabled the introduction of ethanol to the engine. The mechanical governor incorporated in the fuel injection pump caused appropriate reduction in the diesel consumption as the quantum of ethanol induction is increased. Provision was made to measure the cylinder liner temperatures at twenty four points located suitably around the six cylinders. An electrical heater arrangement powered by a 24V battery enabled the heating of the inlet air and the mixture. Fig.1 shows a view of the experimental set up.

RESULTS AND DISCUSSIONS

From the data obtained from the experimental runs the following main observations can be made.

1. With ethanol induction there is a gradual reduction in the diesel consumption at all loads and at all speeds.

2. The specific fuel consumption of the diesel was found to be less when heating of the inlet air was resorted to for all speeds and loads as compared to the fuel consumption when the air was not heated. However the quantum of diesel reduction was significant at higher loads of operation both with and without heating.

3. The consumption of ethanol was found to be more when heating was resorted to and it was possible to run the engine at 5 to 10% overload under such condition for the various speeds.

The effect of heating the mixture on the cylinder liner temperature levels, the variation of percentage of ethanol induction and diesel reduction for various speeds and loads and the effect of ignition accelerator on the performance of the engine are presented and discussed. The characteristics of the engine at 1600 rpm are shown in Fig.2.

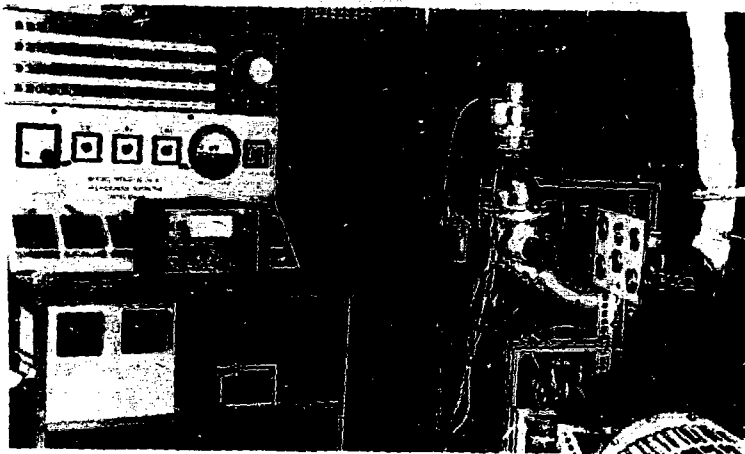


FIG.1. Experimental Setup

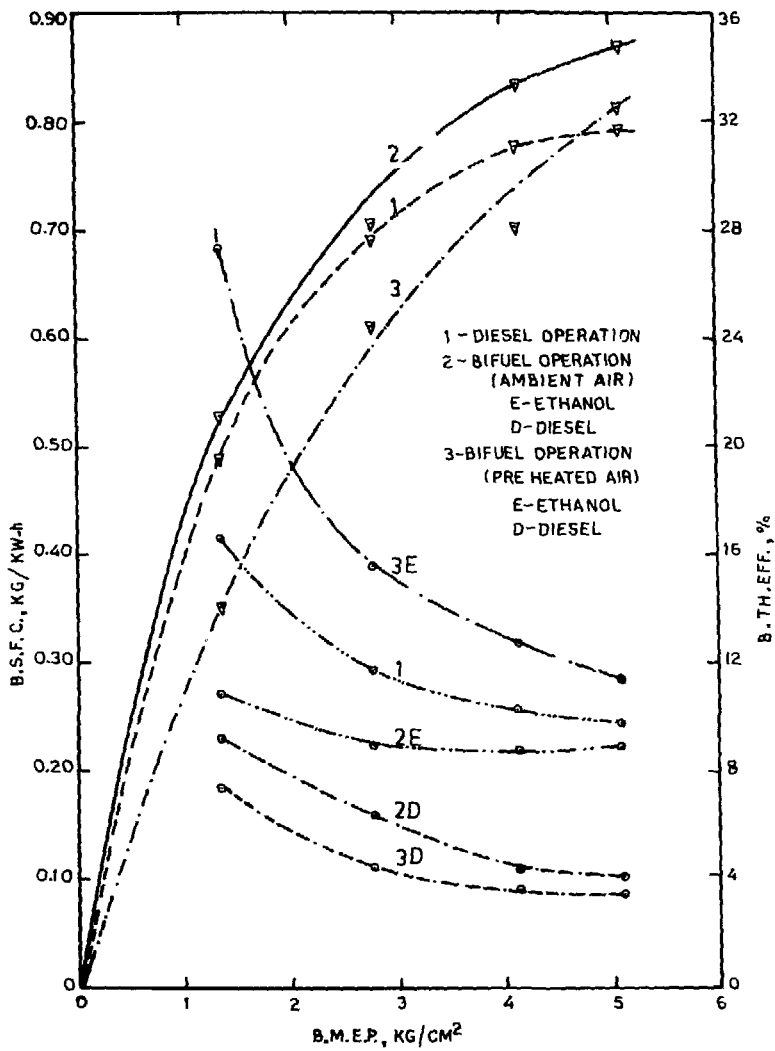


FIG.2 FUEL CONSUMPTION AND BRAKE THERMAL EFFICIENCY AT 1600 RPM

USE OF VEGETABLE OIL FUELS IN DIESEL ENGINES-OPERATING EXPERIENCE

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EXTENDED ABSTRACT

The use of crude vegetable oils as fuels for diesel engines is currently attracting more attention within the agricultural community than highly touted ethanol. This interest stems from the fact that most farm equipment is powered by diesel engines. Diesel engines cannot use ethanol or ethanol based fuels efficiently without extensive modifications. However certain vegetable oils are readily "digested" by diesel engines with minimal difficulty. The miscibility of vegetable oils with conventional mineral based diesel fuels in any proportion greatly enhances its utility as an alternate diesel fuel. And the ability to mechanically extract oil from certain oil-seeds, such as sunflower seed, provides the farmer with an on-the-farm fuel production opportunity and a buffer from supply disruptions of conventional diesel fuels. [1]

The use of vegetable oils in compression ignition (diesel) engines was apparent several decades after the commercial advent of Rudolf Diesel's invention. The first diesel engine delivered to Argentina was fueled with castor oil during a test in 1916. [2] Considerable activity was evident in the investigation and use of vegetable oils for motor fuels during the period 1920 - 1947. [3] Divergent paths were taken in preparing vegetable oils for use in internal combustion engines. In some countries, particularly in the Orient, vegetable oils were either thermally or catalytically cracked yielding primarily olefins and some aromatic and paraffinic hydrocarbons. These, in turn, were fractionated into products resembling gasoline and gas oils. [4] In other areas, notably Europe, Africa and Australia, crude vegetable oils were used directly as fuels for diesel engines. In many cases World War II disrupted the supply of petroleum derived diesel fuels and prompted the switch to vegetable oils. [2,5,6]

Generically, vegetable oils are known as lipids, fatty acid triesters, or triglycerides. Vegetable oils with high calorific value, and seemingly best suited for use as diesel fuels, are low in polyunsaturated fatty acids. There appears to be a relationship between a vegetable oil's fatty acid profile and its cetane rating. Vegetable oils are known to consist almost exclusively of straight-chain acids. Only in a few isolated cases are any ring compounds found to occur as part of the fatty acid molecule. This aspect is a desirous property of diesel fuel as the presence of aromatics encourages the formation of smoke in diesel engine exhaust and is suspect of creating carcinogens.

Historically diesel engines have performed well with minimal combustion chamber deposits and corrosion when fueled on oils with low iodine value [5,6] but experienced combustion difficulty, internal fouling and corrosion

when operating on oils with high iodine value. [2,5] To insure the longevity of personally owned automobile and tractor diesel engines only peanut oil and southern grown sunflower oils, which typically have low iodine values, have been used extensively as diesel fuels. A limited amount of waste soybean cooking oil has been used, but the large amount of animal fat present has presented handling difficulties. The peanut and sunflower oils have been obtained from oilseed crushing plants which cook the oilseeds prior to mechanically expelling the oils. This oil rendering procedure minimizes the oils' phospholipid content and reduces its gumming and corrosion potential when used as a fuel. The oils are stored for a minimum of seven days to allow peanut or sunflower meal to settle to the bottom of settling containers. Oils are pumped from the upper portion of the settling containers to polyethylene storage containers and transferred to the tractor or automobile fuel tanks as required.

Vegetable oils are routinely used as a fuel in a tractor engaged in farm work and an automobile used for personnel transportation. The tractor's engine is a four cylinder, liquid cooled, naturally aspirated, direct injected diesel with a distributor injection pump. The engine displaces 239 cubic inches and has a compression ratio of twenty two to one. The automobile's engine is a four cylinder, liquid cooled, naturally aspirated, indirect injected diesel with an inline injection pump. The engine's displacement is 154 cubic inches and has a compression ratio of twenty one to one. The engine has been equipped with a fuel heater upstream from the primary fuel filter and uses engine coolant as the heat source. An auxiliary fuel tank is installed in the automobile's trunk. An electrically operated fuel tank selector valve is located in the engine compartment and actuated from the driver's seat. A fuel flow totalizer transducer is installed downstream from the fuel tank selector valve (on the supply fuel line) and operates a digital indicator mounted on the vehicle's panel.

Operation of either the tractor or automobile when fueled on vegetable oil is different from operating on No. 2 diesel fuel. Certain precautions are necessary. They arise from the vegetable oil's high flash point and viscosity. The tractor is not operated on one hundred percent vegetable oil unless the ambient temperature is above sixty degrees fahrenheit. It is not equipped with a fuel heater. The automobile's diesel engine is always started on No. 2 diesel fuel and fueled on one hundred percent vegetable oil after reaching a normal operating temperature. Before the engine is stopped it is fueled on No. 2 diesel fuel for sufficient time to purge the fuel injection system of vegetable oil. An exception occurs when engine operation is intermittent and engine temperature does not drop appreciably; the purging cycle is omitted. Below temperatures of twenty five to thirty degrees fahrenheit the vegetable oil's viscosity is too high and cannot be pumped from the fuel tank to the engine. Heaters in the fuel tank and fuel supply and return lines then become a necessity.

From the driver's seat the performance of either engine does not seem impaired when operating on vegetable oil. There is a noticeable decrease in

diesel rattle and exhaust smoke when the indirect injected engine is operating on peanut oil. Under a heavy load the tractor's exhaust appears to be hotter than when operating on No. 2 diesel fuel, but attempts to measure EGT in the field have been inconclusive. The "cooking odor" exhaust due to acrolien is rather apparent. Acrolien is extremely toxic and presents a possible health hazard. However, the tractor's exhaust is odorless when the engine is operating above twelve hundred rpm and under a load. Precise measurements of the automobile's fuel mileage using weighed samples of peanut oil and No. 2 diesel fuel show a ratio essentially the same as the ratio of the two fuels' calorific value, indicating the engine operates with the same thermal efficiency regardless of the fuel. Acceleration test have further substantiated this observation. After five thousand miles of automobile operation and the accumulation of over one hundred operational hours on the tractor while fueled on vegetable oils or their No. 2 diesel fuel admittures; no deterioration of critical engine components has been observed.

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AVAILABLE TECHNOLOGY FOR INDIRECT CONVERSION OF COAL TO METHANOL
AND GASOLINE: A TECHNOLOGY AND ECONOMICS ASSESSMENT

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EXTENDED ABSTRACT

In order to properly direct its limited resources, DOE requires a limited assessment of the present state of the art of the most promising of these different coal conversion routes. Such assessments permit better understanding of the relative technical and economic potential of these processes and form an important part of the basis for future programmatic decisions. The objective of the work to be described was thus to review and assess the present state of the art of indirect liquid fuels synthesis, with particular emphasis to be placed upon those processes which produce methanol suitable for use as fuel as the primary or principal product. Potential uses for this product include combustion in peaking-type turbines or liquid-fueled boilers and conversion to premium-grade fuels through the use of upgrading processes such as Mobil-M. The fuel-grade methanol product from many synthesis processes is likely to be contaminated by other light hydrocarbons since few such processes are highly selective; however, when the principal product consisted of storable, fuel-grade liquids, such processes were considered and evaluated.

Following this review and assessment of the fuel-grade methanol synthesis technologies, Fluor Engineers and Constructors, Houston Division, was asked to prepare four conceptual process designs for indirect conversion of a Western subbituminous coal to either methanol or gasoline.[1] They then estimated capital and operating costs for each of the four cases. This information was used by the Oak Ridge National Laboratory (ORNL) to determine the required product selling prices under a "base case" set of financial ground rules. The sensitivity of process economics to changes in a variety of these financial parameters was investigated by performing numerous additional parallel cost determinations for each case. Finally, the results of the project were examined in an attempt to determine their significance.

The four designs examined in this study included indirect conversion of a generic Western coal located in northeast Wyoming to give the following products:

- methanol production for turbine-grade fuel,
- methanol production for gasoline blending,
- gasoline production with coproduction of synthetic natural gas (SNG),
- gasoline production maximized (via steam reforming of methane).

The total coal feed rate of each of the plants is ~30,000 tons per stream day (TPSD) as received. Lurgi-dry ash gasifiers, ICI methanol synthesis, and the Mobil methanol-to-gasoline (MTG) process are used.

Results of the study, which are given in an upcoming ORNL report,[2] show that a plant for production of 54,000 barrels per stream day (BPSD) of turbine fuel-grade methanol (<2 wt% water) would require a capital investment of \$2.1 billion (mid-1979) and an annual operating expenditure of \$330 million. This results in a required methanol product price of \$0.56/gal (\$8.81/10⁶Btu), as shown in TABLE I. Capital recovery charges account for 63% of this price and it is thus highly sensitive to changes in financing arrangements, capital cost estimating errors, or any other assumptions affecting the capital structure. The remainder of the product price is made up of feed coal cost (20%) and other operating costs (17%).

If the turbine fuel-grade methanol plant is redesigned to produce gasoline blending-grade methanol, the resulting increases in capital and operating costs (\$2 million and \$0.1 million, respectively) are so small that the required product price is hardly changed. On the other hand, if facilities for conversion of the methanol to gasoline (using the Mobil MTG process) are included, the capital and operating costs are more strongly affected becoming \$2.4 billion and \$335 million respectively. This results in the production of 24,200 BPSD of gasoline product having a required selling price of \$1.25/gal. The financial assumptions used are the same as before, except that SNG must now sell for \$8.70/10⁶Btu since the price of gasoline has risen to \$10.88/10⁶Btu.

Of crucial importance to this analysis is the assumption that coproduct SNG will be priced as a premium fuel. In order to eliminate the dependence of gasoline product price on SNG market price, one could design the plant to reform all methane to synthesis gas, which could then be used to produce additional gasoline. However, the penalties for doing so are severe: required capital investment becomes \$2.8 billion, operating costs are \$375 million annually, and the required gasoline selling price rises to \$1.59/gal. Another measure of the adverse effect of the SNG reforming step is shown in the summary table for these processes (TABLE I), where the thermal efficiencies for the four conceptual designs are seen to be 65, 65, 62, and 50 percent respectively.

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TABLE I. BASE CONDITIONS RESULTS FOR FOUR LIQUEFACTION CASE STUDIES
(IN MID-1979 DOLLARS)

Case description	Methanol production for turbine- grade fuel	Methanol production for gasoline blending	Gasoline with coproduction of SNG	Gasoline production maximized
Products				
Methanol (BPSD)	53,500	52,770	---	---
Gasoline (BPSD)	---	---	24,160	42,580
SNG (10^6 scfd)	153	153	159	19
Overall thermal efficiency ^a	64.8	64.8	61.6	50.4
Total capital cost (10^6 \$) ^b	2,130	2,132	2,382	2,784
Annual operating cost (10^6 \$) ^c	331.0	331.1	334.8	375.4
Production prices for base case^d				
Methanol (\$/gal)	0.56	0.57	---	---
Gasoline (\$/gal)	---	---	1.25	1.59
SNG (\$/ 10^6 Btu)	8.02	8.02	8.70	11.10

^aBased on HHV of products/HHV of feed coal.

^bThis includes a 20% estimating allowance.

^cBased on a stream factor of 95% for methanol production, 93% for gasoline production with coproduction of SNG, and 90% for gasoline production maximized.

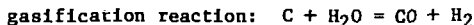
^dBase case assumed: 100% equity financing; 12% annual after-tax rate of return on equity; 1990 price scenario given in ref. 3; 25-year operating life; 5-year construction; 48% federal income tax; 3% state income tax; 2.75% local property tax and insurance; mid-1979 dollars; sum-of-years' digits depreciation for 16 years; \$1/ 10^6 Btu coal; no salvage value.

NON-FOSSIL ENERGY FOR THE PRODUCTION OF SYNTHETIC FUELS FROM COAL
1. FUSION POWER WITH HIGH TEMPERATURE STEAM ELECTROLYZER AND GASIFIER

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EXTENDED ABSTRACT

It is generally agreed that to relieve the world's dependence on the dwindling supply of natural oil and gas resources, it is important to begin deriving the world's liquid and gaseous fuel requirements by converting the world's coal resources to synthetic liquid and gaseous hydrocarbons. The mechanism for converting coal to the clean and convenient synthetic gasoline, methane and oil is to increase the hydrogen to coal ratio (H/C) in raw coal which usually has a value of 0.8 to a value of 1 or more. Thus most coal conversion processes require the use of substantial quantities of hydrogen. In the conventional processes this hydrogen is usually derived from the water-gas reaction with coal. The water is essentially reduced by the carbon in coal to hydrogen and the carbon is oxidized first to CO in the gasification reaction and subsequently to CO₂ in the water gas shift reaction.



The gasification is highly endothermic and requires temperatures in the order of 900° to 1000°C. This energy is provided by burning additional in-situ amounts of coal with oxygen and in order not to dilute the hydrogen with nitrogen the oxygen is separated from the nitrogen before use in an air liquefaction plant. Thus additional amounts of coal are required to provide the endothermic heat of reaction and to provide power to drive the air liquefaction plant. In a conventional plant as much as two-thirds of the coal does not appear in the liquid and gaseous products and is wasted in the formation of CO₂. The subsequent reforming of H₂ and CO to methanol, gasoline or methane fuel in indirect processes or in direct coal hydrogenation processes are exothermic and do not require additional amounts of energy.

Non-fossil energy sources can substantially reduce the requirements of coal for synthetic fuels. These sources include mainly nuclear fission, nuclear fusion, solar energy and hydropower. Each of these sources have unique features for the gasification and conversion reactions. Nuclear fission through light water reactors (LWR) can provide electrolytic hydrogen and oxygen for the coal gasification reaction. Nuclear fission

through the high temperature gas cooled reactor (HTGR) can provide the endothermic heat of gasification by indirect means. Fusion Energy through high temperature electrolysis (HTE) can provide the hydrogen and oxygen and through the high temperature steam gasifier (HTS) can provide the exothermic heat of reaction. Solar energy through direct solar heating can provide the endothermic heat for gasification. Hydropower can provide the hydrogen and oxygen for gasification and for direct hydrogenation.

In this present study the fusion reactor is examined for synthetic fuel production. Fusion reactors could displace a large amount of the coal needed for synthetic fuel production. A unique feature of a fusion reactor is that it can potentially supply high temperature steam in the range of 1000° to 1500°C in a continuous manner. The high temperature steam would be obtained by internal heating of a refractory containing blanket section which would absorb the neutrons from the plasma. The water process stream would absorb the heat from the refractory, producing high temperature steam. The high temperature steam could be electrolyzed in a high temperature electrolyzer (HTE) and converted in a high temperature steam gasifier (HTSG) with coal. The HTE has the advantage of producing H₂ at 50 to 70% overall thermal efficiency. The HTSG has the advantages of eliminating the need for oxygen and excess coal to provide the endothermic heat of reaction for the water gas reaction. No switching valves or heat transfer surfaces are needed. Applying the fusion reactor in combination with HTE and HTSG for conversion of coal to Synthetic Natural Gas (SNG) and liquid gasoline the efficiency of utilization of coal could be improved from 1.6 to 3.2 times for SNG and from 1.8 to 2.4 times for liquid fuel. The major advantages of the fusion reactor HTE-HTSG system for synthetic fuels includes (1) an increase in utilization of the coal resource by a factor of 2 to 3 respectively for liquid and gas production (2) a 2-to 3-fold reduction in the environmental pollution factors which include (a) reduced mining hazards, (b) reduced release of the toxic agents, S, N and ash and (c) reduced buildup of CO₂ in the atmosphere which could lead to a catastrophic climatic "greenhouse" effect. The combined fusion reactor-coal system becomes economically competitive with conventional all-coal systems above a cost of coal in the range of 28 to \$46/ton where the cost of the fusion reactor is charged at \$400/Kw(t). Approximately 200 fusion reactors (3890 MW(t) each) combined with 300 million tons of coal could supply all the natural gas consumed in the country in 1977. Approximately 100 fusion reactors (6130 MW(t) each) combined with 394 million tons of coal could supply all the gasoline consumed in 1977. Current coal production capacity would be ample for producing all the gaseous and liquid fuel in the country.

PULSED ELECTRON BEAM IRRADIATION OF
COAL TO PRODUCE SYNFUELS

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ABSTRACT

State of the art pulsed electron generators are capable of producing megamp electron beams of sub-microsecond duration and megavolt energies. The effect of irradiating coal slabs with this type of beam is to produce rapid bulk heating (approximately 600°C) by electron energy deposition during the pulse duration to a depth of several tenths of an inch which is the range of megavolt electrons in coal. Furthermore, the rapid bulk heating produces a thermal and mechanical shock to the coal which results in a pulsed pressure increase of several hundred atmospheres and subsequent blow off or spall of the irradiated material. Laboratory measurements of this effect on concrete slabs is presented.

A near state of the art 2 MEV electron pulsed beam generator producing fifty 1 megajoule pulses/sec with a beam cross section of 2 square feet is considered as the energy source for the low temperature carbonization of a weakly caking coal having a volatile content of about 30 percent. The product yields comparable to those obtained by the Brennstoff-Technik process* are estimated and compared with the electrical power requirements of the beam generator. A conceptual design of the front end hardware for a pulsed electron beam synthetic fuel facility is presented.

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Arc-Coal Chemicals:
A Feasible Alternative to Petroleum-Based Chemicals

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The Avco Arc-Coal Process produces acetylene, hydrogen, carbon monoxide, hydrogen cyanide, carbon black, sulfur, and char by processing pulverized coal in an electric arc reactor. Many of these products are valuable building blocks, and can be used in place of feedstocks derived from petroleum and natural gas in the production of large volume chemicals such as vinyl chloride and vinyl acetate. Different combinations of user plants can be envisaged for a chemicals complex which obtains its feedstocks from an arc-coal facility.

This article briefly described the arc-coal process, and proposes one possible configuration for an industrial chemical complex based on arc-coal chemicals. The complex would consist of an arc-coal plant as well as plants for the manufacture of chlorine, vinyl chloride, acetic acid, vinyl acetate, and methanol. Acetylene from the arc-coal plant is used with chlorine in the manufacture of vinyl chloride, and with acetic acid in the manufacture of vinyl acetate. It is also the raw material for the manufacture of acetic acid. Methanol is synthesized using carbon monoxide and hydrogen produced in the arc-coal plant.

An important part of the industrial complex is a power plant which would operate in a cogeneration mode for improved efficiency, and supply the DC electrical power required by both the arc-coal and chlorine plants. Cogenerated steam from this plant would supply process requirements throughout the complex.

Preliminary economics for the industrial complex are provided.

EFFECT OF EMBEDDED TUBE SIZE ON HEAT TRANSFER
COEFFICIENTS IN A FLUIDIZED BED COMBUSTOR

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EXTENDED ABSTRACT

INTRODUCTION

In recent years, fluidized bed combustion of coal is finding importance for application in steam boilers, as it provides a convenient means of burning low grade coals without pollution. Further, it enables high rates of heat transfer to the embedded tubes. The local heat transfer to embedded horizontal tubes are largely influenced by the hydrodynamic character in the vicinity of the tubes. But, the localised variations in the hydrodynamic behaviour of the bed are dependent to a considerable degree on the tube size and spacing. Hence, a knowledge of the effect of tube size on the variation of local heat transfer coefficients will be of use in optimising the design of heat exchange surfaces and materials used in fluidized bed combustors.

Gelperin et.al [1] studied the distribution of local heat transfer coefficients around the circumference of single horizontal cylinder of diameter 20 to 80 mm in a fluidized bed. They observed that the distribution of the local heat transfer coefficients were more uniform for smaller diameter tubes. Berg and Baskakov [2] also studied the local heat transfer coefficients to the tubes of diameters 20 and 40 mm in the bed operating at room temperature, and observed a similar trend. But in these studies, the fluidized beds were at low temperatures. Consequently, the data available on the contribution of radiation to the local heat transfer rates to the embedded tubes in fluidized bed coal combustors are very meagre.

With this in view, experimental investigations were carried out to study the effect of tube size on the local variation of radiative and total heat transfer coefficients around the circumference of a single embedded tubes of different diameters in a fluidized bed combustor.

EXPERIMENTAL APPARATUS

The experiments were conducted in a square water jacketed fluidized bed column, constructed of 3 mm thick mild steel plate, with inside dimensions of 300 x 300 mm. The height of the bed was 300 mm and the free board height was 600 mm. The distributor plate was a perforated steel plate with 19% of its area open for air flow. Coal was fed to the combustor by a screw feeder. Tubes of outer diameter 60, 50, 42 and 32 mm were embedded in the bed, one at a time.

HEAT TRANSFER MEASUREMENT

The overall heat flux to the tube was measured by a flux meter employing a differential thermocouple fixed to the ends of a steel sensing plug. One end of the plug was exposed to the combustor bed while the other was cooled by water at a constant temperature of 40°C circulated from a thermostat pump. The radiative heat transfer to the tube surface was measured by a radiometer, employing a thermistor as the sensing element. A quartz glass plate was used to filter the incident conductive heat flux. The thermistor and the quartz glass plate were housed inside a housing, which was cooled by water at 40°C circulated from a thermostat pump. These meters were calibrated employing a hohlraum as the standard source of heat. The tube surface temperature was measured by an insulated chromal-alumel thermocouple. The above instruments were mounted flush with the outer surface of the tube.

EXPERIMENTAL RESULTS

Experiments were conducted at fluidizing velocity of 1.2 m/s with coal particle size of 6-0 mm and bed temperature of 750°C. Under these operating conditions the local values of total and radiative coefficient varied by 50 and 60 percent respectively from their mean values for a tube size of 60 mm outer diameter. As the tube size decreased, the contribution of the radiative coefficient to the total heat transfer was found to remain virtually the same. But the degree of local variation of the total and radiative coefficients were found to decrease, resulting in more uniform heat flux conditions for smaller tubes.

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SOME CHARACTERISTICS OF A SPOUT-FLUID COAL COMBUSTOR

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Experiments were carried out to determine some of the important characteristics of the spout-fluid bed combustor. The spout-fluid contacting system combines the spouted bed mechanism with the usual fluidized bed technique. This hybrid operation has been recorded in the recent literature as a spout-fluid bed. [1], [2], [3]

This energy processing system can be operated in four modes which are available to the process designer and plant operator in order to treat gases and/or solids in specific chemical procedures. The bed may be operated in the packed bed mode in order to initially ignite the coal; then spout the packed bed in the second phase in order to thoroughly mix the system; in the third phase the bed may be fluidized during the combustion cycle with the major heat release occurring in the sequel; finally ash may be ejected, but combustion continued, by using the fourth phase, the spout-fluid mode. Attached Figure 1 indicates the solids and air flow in this unit with a cone bottom; this research used a flat bottom.

Pre-ignition research has occurred in an attempt to ascertain combustor mixing, attrition characteristics, velocity and temperature profiles. Pressure drops in the spout, fluidized and SF beds were determined as a function of air flow rate.

The bed material used in all of the above systems was principally of two types: coal-sand mixtures and wheat.

This research was partially supplied by the Grants In Aid For Education Program of the Bethlehem Steel Corporation.

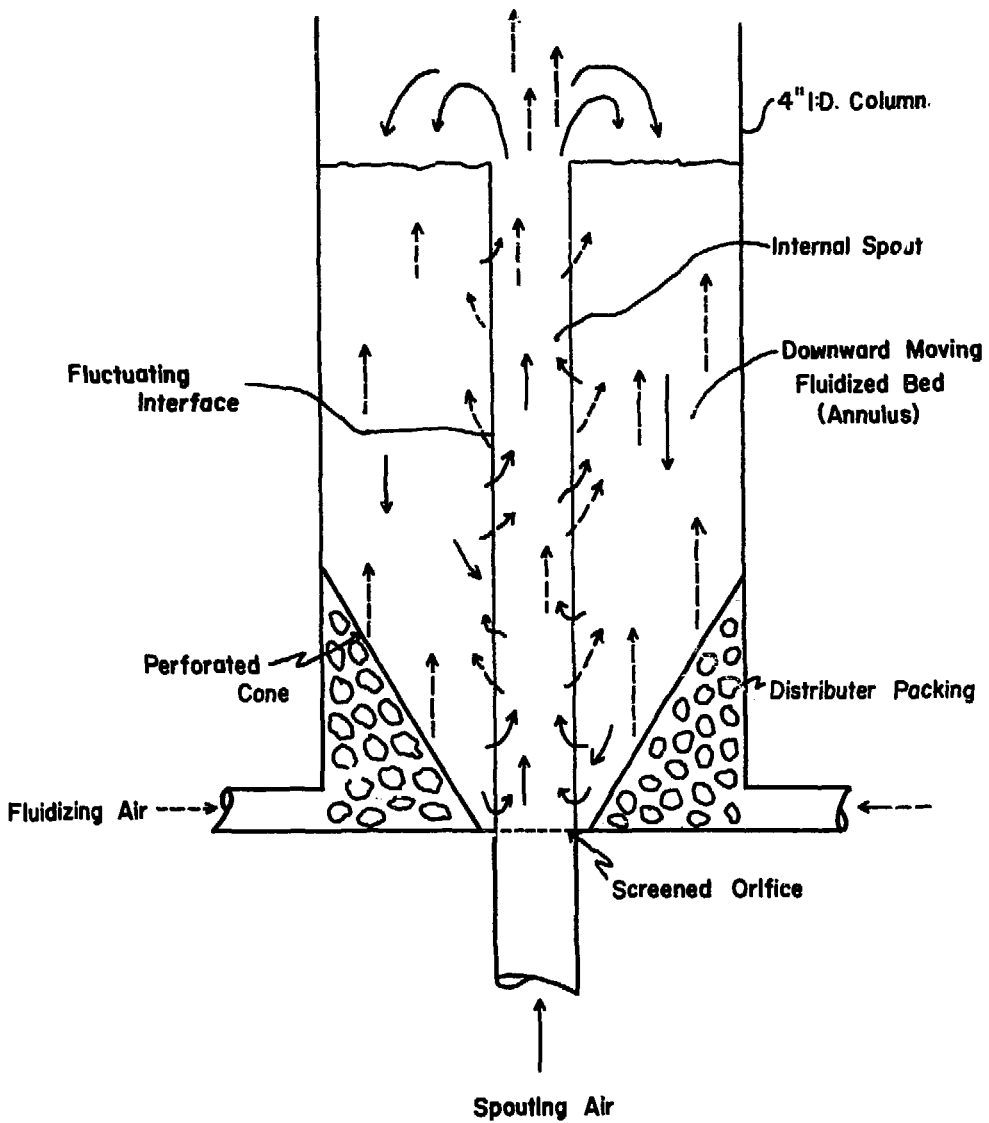
The results of this work indicate that

- the mixing process in the SF bed is extremely rapid. For 4" bed depths of packing in a 4" (inside diameter) plexiglas column the time to reach steady state (oscillating with time) was from 15 to 20 seconds. This compares favorably with the fluidized bed under the same experimental conditions
- attrition of coal in the SF bed for coal-sand mixtures is approximately the same as the fluidized bed under the same operating conditions
- the SF bed has within it three possible regions to analyze: the central internal spout, a buffer or transition region and finally the fluidized annulus region.
- momentum transport through the three regions is presently difficult to mathematically model with a single equation. Three tentative velocity profile exponential models are shown for the bed.
- heat transport in the three regions has been approximately modeled, with again the two inner regions modeled by exponential functions. Further research is being done in this area.

The SF mechanism finally should be developed mathematically so that the defining functions are radially continuous across the three regions. The work of J.D. Murray [4], which mathematically defined fluidization as a continuum phenomenon, may be indeed effective in describing, as he states, general dispersed two-phase flow.

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Schematic Diagram of a Spout-Fluid Bed

MATHEMATICAL MODELLING OF COAL FIRED
FLUIDISED BED COMBUSTORS

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EXTENDED ABSTRACT

INTRODUCTION

In recent years, as increasing emphasis has been placed in energy conservation and air pollution, fluidised bed combustion has become a promising technology for burning coal in industrial and utility boilers.

Although much useful information has been obtained particularly from bench or pilot scale experiments, the development of suitable mathematical models to aid design has not been forthcoming. This is partly owing to the complex coupled phenomena involved in the process of fluidised combustion. It involves the interdependence of fluid mechanics, various modes of heat and mass transfer and chemical kinetics. A limited number of models have already been reported in the literature [1-3]. However, at the present time, an industrial designer cannot predict from the first principles the behaviour of continuous fluidised bed combustors burning coal of wide size distribution. The objective of this study was therefore to develop a system model describing the behaviour of continuous coal fired fluidised combustors and to use this model for the prediction of effect of excess air and recycle on the behaviour of a pilot scale coal fired fluidised combustor.

SYSTEM MODEL

The behaviour of continuous fluidised bed combustors burning coal of wide size distribution is described by a system model based on conservation equations for energy and chemical species. The model predicts the profiles of concentration and temperature in the bed and hence the exit gas composition, the combustion efficiency, the bed carbon content, percent carryover loss and size distribution of particles in the bed and the carryover, provided that the input data on bed dimensions, superficial velocity, size distribution and analysis of coal feed and characteristics of inert bed material are supplied.

The system model consists of three main components: fluid mechanics, combustion and heat transfer. With regard to the fluid mechanics component constant uniform size bubbles are assumed throughout the bed. The bed is

assumed to be aggregatively fluidised and is treated by the Davidson-Harrison two phase model.

As for the second component of the model, single particle combustion, instantaneous devolatilisation of the coal particles, constant density of the burning particle, and two heterogeneous reactions of first order at the particle surface are considered. Bed particle size distribution is calculated from the population balance.

With regard to the final component of the model, heat transfer, the thermal energy balance on the bubble and emulsion phases and on the particle surface considers convection and heat generation by the combustion reactions.

For the application of the system model, advantage was taken of the data previously reported in literature on a pilot scale coal fired fluidised bed combustor [4].

CONCLUSION

A system model of continuous fluidised bed combustors burning coal of wide size distribution has been derived, and applied to the investigation of the effect of excess air and recycle on bed concentration and temperature profiles, the combustion efficiency, carryover loss, size distribution of particles in bed and in carryover, and char loading in bed. To demonstrate the effect of recycling, the behaviour of the fluidised combustor has been predicted for two extreme cases of recycle: complete and no recycle of elutriated char particles, the former was chosen to determine the behaviour of the model in the absence of elutriation, and the latter corresponds to the actual operating conditions of the fluidised combustor. Expected trends for concentration and temperature profiles and combustion efficiency are predicted correctly for both cases. The predictive ability and the flexibility of the model for incorporation of refinements such as a correlation for bubble growth and a detailed combustion mechanism, makes the model a promising one for the evaluation of performance of the fluid bed industrial boilers.

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PRESENT RESEARCH ADVANCES IN COAL-BURNING GAS TURBINES[†]

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EXTENDED ABSTRACT

The use of pulverized coal as fuel in many power plants is inevitable both in the present and in the future. The products of combustion will contain solid particles, whose presence cause erosion of the engine components and in a very short time possible deterioration of the power output. Air filtration cannot accomplish a 100 percent removal of the particles, and results in performance reduction. In coal gasification, both the coal and the catalyst contribute to the resulting particulate flow. While larger particles can be removed by cyclones, a quantity of particles ranging in size between 1 and 15 microns diameter still pass through the cyclones and enter the turbine resulting in a very limited life of this component. On the other hand, the severe erosion of the compressor and turbine components of helicopter and aircraft engines is caused by their operation in dusty environment. Both the engine performance and the engine life are adversely affected by the erosion of these components. The future of advanced turbomachinery for use in the coal industry, gasification, mining pipeline's gas transport, powder coal burning, coal-oil gas refinery, aircraft engines, and many other applications is dependent upon the understanding of the fundamentals of erosion phenomena.

Two problems are involved in the erosion prediction. First the velocity, direction and number of particles striking the surface must be determined. The second part involves the calculation of the surface material removed using the information obtained from the first part.

In order to understand and predict the erosion phenomenon of rotating turbomachines, it is important to study the dynamic behavior of the solid particles which are entrained by the gas flow through the stages of turbines. The effect of different parameters, such as particle mean diameter, material density and initial particle and gas velocities on the particle dynamic behavior are investigated. Results of this study are then used to make observations concerning the areas of the blades or casing that are subjected to erosion by Tabakoff et

[†] This research was sponsored by Department of Energy, Contract No. DE-AC01-76ET10620.

al. in references [1] and [2]. A typical example for the dynamic characteristics of 10 micron particles entrained by the gas through a turbine stage is shown in Fig. 1. It may be seen from this figure that many particles impact on the blades leading edges, pressure sides and the trailing edges. Other particles pass the stage without any collisions with the blade surface. The values for the angle of attack and velocity of each particle just before particle impact on the blade surface is known from the computer calculations. We have developed semi-empirical equations which, with the data obtained from the trajectory calculations, may be used to predict the erosion losses.

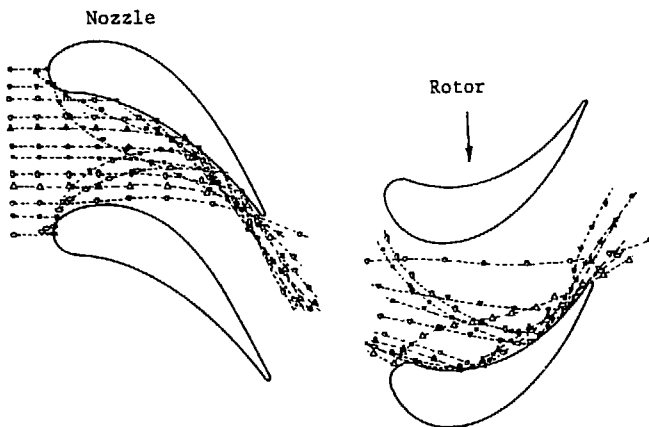


Fig. 1. Turbine Stage Trajectories.

An experimental investigation is undertaken to obtain a basic understanding of the mechanisms of erosion at high temperatures. Therefore, test equipment has been designed to simulate the aerodynamic and thermodynamic conditions in the turbine [3, 4]. This facility has the capability of providing environment temperatures ranging between ambient and 1093°C (2000°F) for erosion testing of various materials. The effects of high temperature on the erosion rate was determined for the following alloys: 304 stainless steel, Rene 41, Ti 6-4 and INCO 718. The fly ash used in this experimental study was with averaged mean particle diameter of 38.4 microns. A series of tests was conducted from room temperature (70°F) to a maximum of 1200°F. The effect of the angle of attack on the erosion rate showed a persistent trend of ductile behavior in the case of all alloys, independent of the magnitude of the particle velocity or the temperature (Fig. 2). Starting from

15° angle of attack, the erosion rate increased until a maximum of about 25°, and then decreased to a residual value at normal impact. The definition of the point of maximum erosion becomes much more explicit with increasing velocity and increasing temperature. Figure 2 shows the erosion parameter for 304 steel for three different velocities and two temperatures (78°F and 1200°F). It may be observed that at the maximum angle of attack (25°) the erosion volume parameter for a particle velocity of 600 ft/sec, from ambient temperature (78°F) to 1200°F, increases almost 2.5 times, and for a velocity of 1000 ft/sec, 6.5 times. The data obtained for different alloys can be used to provide a basis for material selection in future turbines. If erosion could be incorporated as an engine design parameter, perhaps an erosion tolerant engine could be produced.

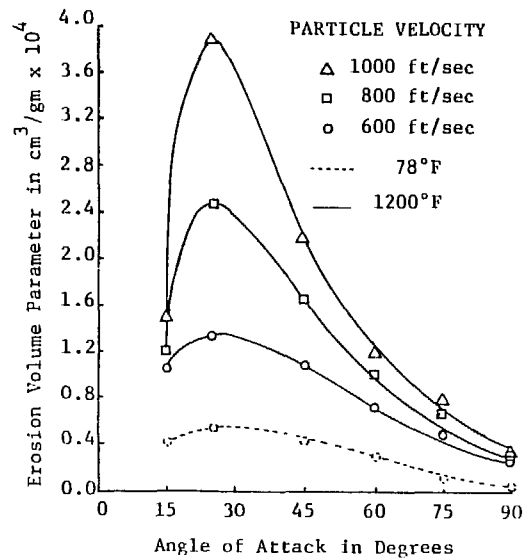


Fig. 2. Effect of Angle of Attack on 304 Steel at 78°F and 1200°F for Different Particle Velocities.

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A MODERN ALTERNATIVE TO OIL-FIRED SHIPS*†

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EXTENDED ABSTRACT

INTRODUCTION

There are presently approximately 30,000 civilian transport ships operating in the world's oceans above 1,000 deadweight tons. These ships are operating on nearly a 50% duty cycle and consume 3.85 millions barrels of oil per day, or roughly 7% of the world's total oil consumption. If an efficient--and environmentally acceptable--means were found to displace this fuel consumption, world oil demand would decrease significantly. A method for doing just this is proposed herein.

Direct coal-fired gas turbines offer a means of powering ships which will become even more attractive as oil prices escalate. These systems are significantly more compact than either marine diesels or steam turbines. Compactness and lightness are important considerations as they help overcome the weight penalty that must be paid for the increased fuel bunkering associated with the use of coal.

Description of the Power Cycle Fig. 1 illustrates the power cycle proposed for a marine coal-fired turbine. Inlet air is initially dried and salt is removed using compressed air which is preheated with the turbine outlet stream. Two-stage compression with intercooling is used. Preheated air enters a pressurized pulverized coal combustor whose outlet temperature is approximately 800°C. Hot gas cleanup follows. Hot gas cleanup is needed in order to limit turbine blade erosion and corrosion to an economically acceptable level. Hot, cleaned gas is then expanded through a turbine, with one reheat, and exits through a stack following preheat. Including parasitic power losses for the hot gas cleanup system, a 30% cycle efficiency appears obtainable using present-day materials and technologies.

* Work performed under the auspices of the U.S. Department of Energy, Washington, DC.

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What makes this power cycle unusual is the method of hot gas cleanup proposed. To date hot gas cleanup has severely limited the practicability of direct coal-fired turbines. In order to trap particulates and trap sulfates, where necessary, the turbine inlet stream is driven through a rotating bed of refractory material, cooling the gas stream. The bed is sized to yield an outlet temperature of $\sim 150^{\circ}\text{C}$. Turbine inlet gas enters the bore of the rotating bed, passes through the bed, and out through a porous drum. Low pressure steam cools the outlet stream to accommodate for conduction through the bed. Now the process is reversed in a second, identical rotating fluidized bed. Here the stream enters through the porous drum and withdraws sensible heat from the bed as it passes through to the center of the bed. By reversing this procedure every ten seconds, as is shown in Fig. 1, the exhaust bed is fluidized approximately 20% affording mixing of the beds, which acts in a manner similar to a ball bed in picking up ash. As bed stirring moves ash towards cooler regions it hardens and is trapped within the bed. By scraping off a portion of the bed and replacing it with fresh refractory, with a mean residence time of 2 hours, the ash and metals are removed from the hot gas stream. The two-way valves have to support a pressure of a few psi and can operate successfully with .5-1% through leakage. Therefore, while high throughput, high-temperature valving is generally difficult, the lax requirements placed upon the valve performance make this less of a concern.

Economic Considerations Two cases have been investigated for evaluating the payback on a direct coal-fired turbine. The first case is that a 20,000 DWT cargo ship with a 16,000 SHP diesel engine; cruising at 18 1/2 knots. The second case is that of a 250,000 DWT merchant tanker with a 60,000 SHP diesel engine cruising at 17 1/2 knots. A route of 4,000 nautical miles with a four-day layover at each end is considered. The cargo vessel accomplishes thirteen trips per annum and the merchant tanker twelve. All remaining time is allowed for dry docking and standby. In comparing competing energy sources and power cycles, it is assumed cargo carrying capacities remain fixed. Any weight penalty results in increased displacement and power requirements. It is, therefore, possible to neglect freight rates in calculating fuel cost saving [1]. A further assumption that costs associated with crew, stevedoring, port and light dues, and wharfage are independent of engine type.

Oil-fired diesel engines are assumed for both the cargo and tanker cases. In both cases oil consumption is taken to be 0.4 lb/SHP hr. [2]. Engine weight is taken to be 150 lbs/SHP [2].

Bunkering of fuel for a one-way trip is assumed for diesel power and both legs must be carried on a coal-powered ship. This is due to the greater availability of oil at all ports at the present time. Bunkering of refractory (e.g., calcium silicate, which gets SO_2 as well) adds a further 5% weight penalty to coal. Even so, the power penalty is roughly 1-2% for both cases.

A discount rate of 10% is assumed. It is also assumed that the cost of oil is rising at 3% above the discount rate and the price of coal is rising at 2% above the discount rate. Contract prices for coal and diesel oil are taken to be \$30 and \$291 (\$/gallon) per tonne, respectively. For a ten-year period of operation the present value of the fuel savings for the cargo ship case is \$49,000,000 and for the merchant tanker \$194,000,000.

CONCLUSIONS

Some technology development is necessary in order to efficiently use coal as an energy source to drive ships. This market represents a significant amount of energy and the payback to the ship owner can be significant.

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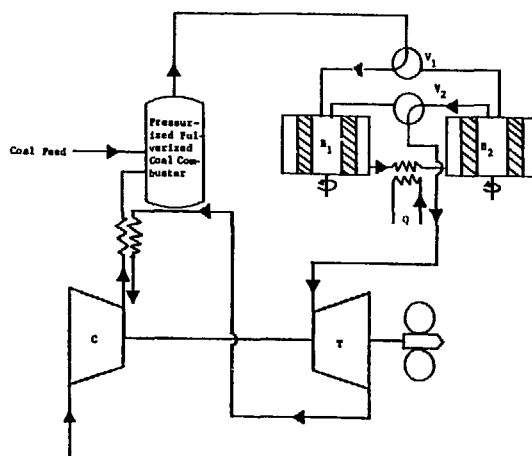


Figure 1 Schematic layout of a direct coal-fired marine turbine including hot gas cleanup.

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SESSION 5E

OIL SHALE PROGRAMS

ORGANIC-RICH SHALE OF THE WORLD LAND AREAS

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EXTENDED ABSTRACT

INTRODUCTION

Organic-rich shale is a fine-grained sedimentary rock containing 5-65% organic matter commonly referred to as "kerogen". When the rock is subjected to heat, the contained kerogen is converted to synthetic oil and/or combustible gas.

Lithologically, organic-rich shales include several kinds of rock such as true shale, impure limestone and even impure coal depending upon the mineral composition of the rock hosting the "kerogen". Further, they have a variety of names which are sometimes ambiguous but are firmly entrenched in common usage. For example, the rock commonly called oil shale is one type of organic-rich shale even though in some areas it may actually be an impure limestone. Other types include black, carbonaceous, bituminous and cannel shales. All have one common characteristic which is important to us all; namely, they are a significant potential source of energy for our future needs.

Oil shale and other organic-rich shale deposits throughout the world range in age from Cambrian to Tertiary (40-600 million years old). The major deposits were formed in large marine basins or embayments and in large lake basins with the deposits extending over thousands of square miles. Many lesser deposits formed in smaller bodies of water such as lakes, lagoons and coastal swamps associated with coal beds.

Of the various types of organic-rich shale, oil shale is probably the most important to our energy needs in the immediate future. Therefore, this report will focus primarily on oil-shale deposits and their resources.

Oil shale yields varying amounts of oil by conventional methods of destructive distillation in a closed retort system. In this report, any organic-rich shale that yields at least 10 gallons of oil per short ton of shale (G/T) is considered oil shale. Thus defined, the term has resource implications only and disregards the mode of origin and lithology of the rock. The 10 G/T grade represents the approximate minimum oil yield of deposits that have been mined on a commercial scale by world shale-oil industries in the past. Thus, they may be considered as potential sources of oil for future development by demonstrated methods.

WORLD-WIDE DEPOSITS AND RESOURCES

In 1965, the United States Geological Survey (USGS) completed an extensive inventory of organic-rich shale deposits underlying world land areas [1]. That excellent inventory is the main reference for the shale-oil resource data presented in this report. However, resource estimates are updated where possible based on more recently compiled information.

Oil-shale deposits grading over 10 G/T underlie portions of six continents; Africa, Asia, Australia-New Zealand, Europe, North America and South America. The total in-place resources of these deposits are about 342 trillion barrels of shale oil with about 3 trillion barrels known and 339 trillion barrels inferred. Of the total, 712 billion barrels are estimated recoverable.

North America leads in both known in-place and recoverable resources based primarily upon the prolific oil-shale deposits of the Green River Formation in the United States. Asia ranks first in both inferred and total in-place resources suggesting that it has great potential for significant development in the future.

UNITED STATES DEPOSITS AND RESOURCES

Oil-shale deposits grading over 10 G/T underlie substantial portions of the United States with their locations ranging from coast to coast. The total in-place resources of these deposits are about 28 trillion barrels of shale oil with about 2 trillion barrels known and 26 trillion barrels inferred. Of the total, about 600 billion barrels are currently estimated recoverable, all from the Green River Formation deposits.

Estimates of recoverable resources from all United States deposits other than from the Green River Formation are currently ranked as "small". Some of these estimates may experience upgrading in the future as additional resource information is compiled and the technology of mining and processing advances.

GREEN RIVER FORMATION DEPOSITS AND RESOURCES

The Green River Formation underlies about 16,000 square miles of several basins in the tri-state area of northwest Colorado, northeast Utah and southwest Wyoming. It was deposited some 50-60 million years ago during the Tertiary Period in two vast intermountain basins, one covering parts of northwest Colorado and northeast Utah and the other centered in southwest Wyoming. The formation's oil shales were deposited in extensive lakes which occupied the low central portion of each of the two basins.

Lithologically, most Green River oil shale is dolomitic marlstone, a clay-rich fine-grained limestone containing variable amounts of organic matter (kerogen). This organic matter was derived chiefly from the remains of algae, aquatic organisms, wax, spores and pollen grains.

Nowhere in the world is there another oil-shale deposit that rivals that of portions of the Green River Formation considering the combined parameters of areal extent, thickness and richness of grade. In higher-grade shales over 15 G/T, the formation's known in-place resources are about 1.8 trillion barrels of shale oil, of which one-third or 600 billion barrels are estimated recoverable. The most prolific deposits are in the Piceance Creek basin where one well penetrated a continuous oil-shale interval over 1,900 feet thick grading an average of 25 G/T oil.

Considering only known in-place resources, the Green River Formation accounts for 2 trillion barrels or 61% of the world's 3.3 trillion barrels in shales grading over 10 G/T. In terms of recoverable resources, the formation accounts for 600 billion barrels or 84% of the world's 712 billion barrels. Even if the formation's recoverable resources were decreased by half to 300 billion barrels (thus reducing the world's recoverable resources to 412 billion barrels), it would still contain a substantial 73% of the world's recoverable resources.

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OIL SHALE - A NEW FRONTIER

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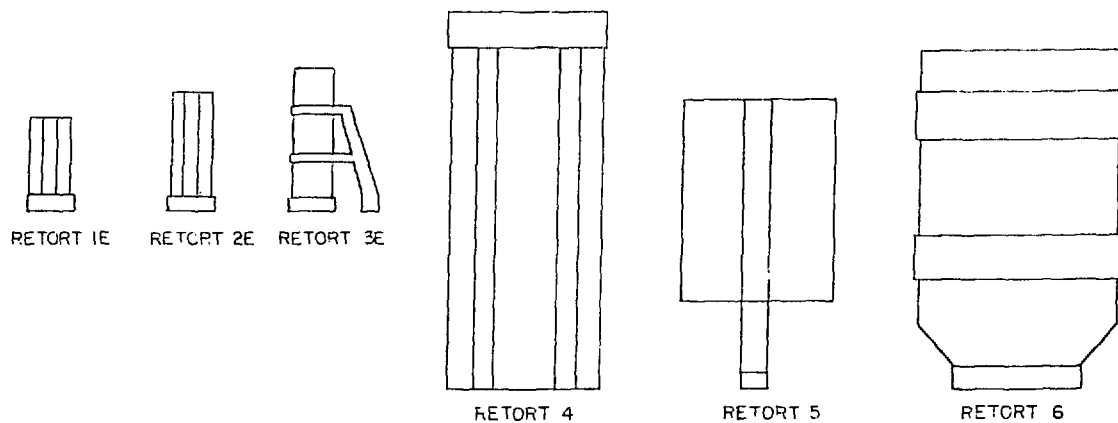
EXTENDED ABSTRACT

Occidental began its development of the Modified In-Situ retorting process in the late 1960's. The first field work commenced at the Logan Wash property in 1972. Three research retorts were constructed and burned, utilizing two different methods of forming the retort (Figure I). Following this successful research work, three commercial sized retorts were constructed.

Over 100,000 barrels of oil have been produced to date. Two additional full-scale retorts are under development at Logan Wash (Figure II).

The results of the Logan Wash program are being used in the design and construction of the C.B. Federal Prototype Lease Tract. This 5,000 acre tract is leased to the Cathedral Bluffs Shale Oil Company, a partnership between Tenneco and Occidental, with Occidental as the operator, by the Department of Interior. Site work began in 1977 and currently three (3) large shafts are being sunk to a depth of about 1900 ft. to access the oil shale formation.

The operation will commence in 1985 and reach full production in 1990. Both Modified In-Situ and surface retorting will be used to produce a nominal 100,000 barrels per day. The mine will hoist 60,000 tons per day and will use 3400 underground workers in the mining, construction of the retorts, and the operation of the retorts. This combination of underground activities creates a unique challenge to the design and operation of such a facility.



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RETORT	1E	2E	3E	4	5	6
DIMENSIONS	31' x 31' x 72'	32' x 32' x 92'	32' x 32' x 113'	120' x 120' x 298'	1.8' x 1.8' x 217'	162' x 162' x 270'
OIL REC'V	1250 bls	1424 bls	1616 bls	27,500 bls	11,300 bls	48,000 bls
YEAR PROC.	1973	1974	1975	1975	1977	1978

FIGURE 1

Retorts 7 and 8

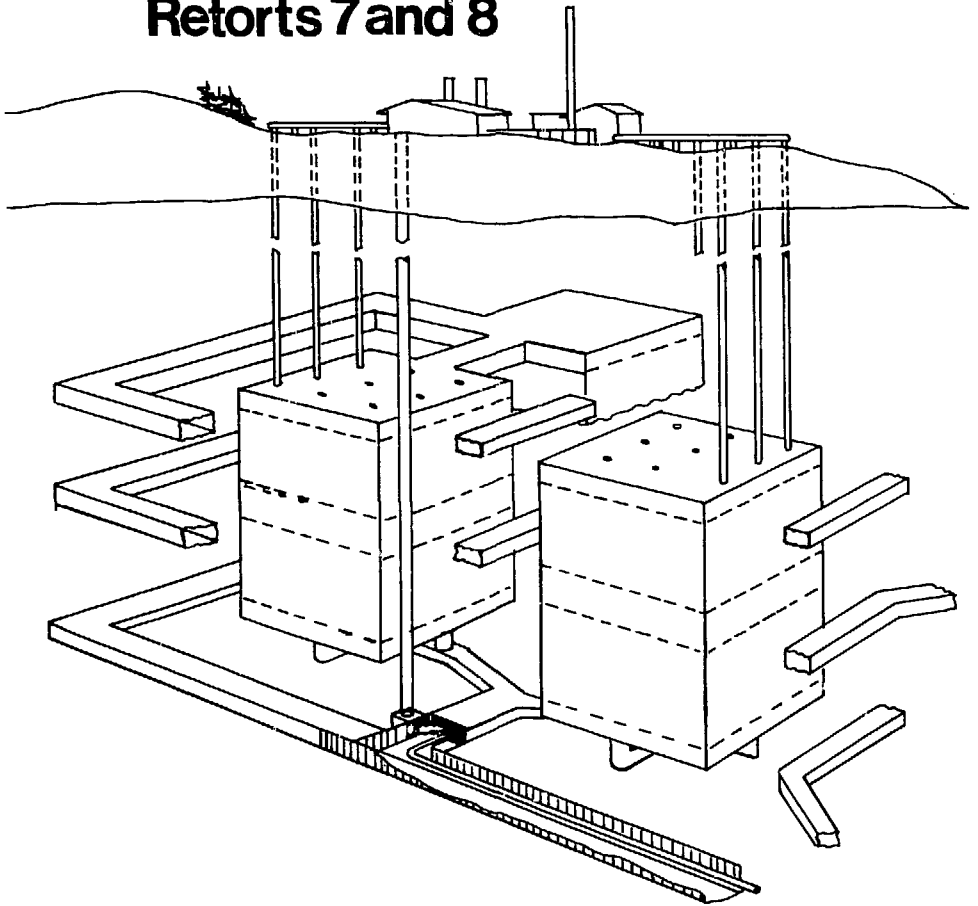


FIGURE II

"RIO BLANCO PROJECT"

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EXTENDED ABSTRACT

The Rio Blanco Oil Shale Company is a general partnership of Standard Oil Company (Indiana) and Gulf Oil Corporation. Rio Blanco was formed specifically to develop Federal Prototype Oil Shale Tract C-a in Colorado.

In 1974, the United States Department of the Interior launched its Federal Prototype Oil Shale Program to test the environmental and economic feasibility of oil shale development. Six tracts were offered for lease. However, only four attracted bids. The leases were selected to test various mining and processing technologies. C-a, the tract leased by Gulf and Standard, was expected to be an open pit mine with surface processing. Others were to test different technologies.

All of the leases contain about 5,000 acres or eight square miles. On Tract C-a, there are some estimated nine billion barrels of shale oil in place. The amount which can be recovered depends on the mining method used. The best recovery comes from open pit mining where more than 5 billion barrels could be obtained. Modified in situ would produce around 2 billion barrels and room and pillar mining would only permit the recovery of a billion barrels.

When the lease was acquired in March of 1974, it was expected that development would be by open pit mining methods and surface retorting. Prior to offering the prototype leases, the Department of the Interior had completed a six-volume Environmental Impact Statement (EIS) covering the area involved. In addition to making it very clear that C-a should be an open pit test, the EIS stated clearly in several places that off-tract location of processing facilities and disposal of processed shale and overburden would be likely in order to assure maximum resource development.

Rio Blanco's plan included initial commercial operation of 50,000 barrels per day. Both the processing facility and the disposal area were located off-tract.

In 1975, the Solicitor of the Interior Department ruled that the Secretary did not have the necessary authority to make off-tract land available. Therefore, the Department drafted enabling legislation for Congress. It was introduced in both houses of Congress, but never got out of committee.

In 1976, the Rio Blanco Oil Shale Company requested and was granted a suspension of operations from the Interior Department and proceeded to

reexamine other potential technologies. In that year, it was determined that the modified in situ technology seemed to have some advantages although it would result in less resource recovery. In May of 1977, a revised Detailed Development Plan was submitted to the Department of the Interior calling for modified in situ (in place) development of Tract C-a.

The plan called for production of some 57,000 barrels of shale oil per day from underground and 19,000 barrels per day from surface retorting of 20% of the shale removed from the retorts to create void space.

Underground burning of a retort requires that it be rubbled so air space can be created in the shale rock. The retort is then ignited at the top and the downward passage of the flame is controlled by air and steam. In the combustion zone, the temperature ranges between 1400° and 1800° F. However, since only 500° to 900° is required to free the shale oil, it will escape from the rock in the form of a vapor in advance of the flame front. As the vapor is forced downward away from the retorting zone, it will condense into liquid. After flowing down through the retort to a room to separate oil and water, the oil will be pumped to the surface. Gas produced with the oil will be piped to the surface for cleanup and use.

Early in 1979, Rio Blanco purchased use rights to certain modified in situ technology of Occidental Oil Company. However, Rio Blanco is developing its own approach to MIS which includes a high void system. About 30% of the target ore is removed before retorting. The first small retort in a demonstration program was burned this past fall. It was 166 feet high and 30 feet square. Information from that burn will be employed in the next two retorts which are planned at about 400 feet tall. They are scheduled to be burned before the end of 1981.

Operating problems so far have been primarily due to the presence of underground aquifers. Special attention has had to be given to mine dewatering.

In 1979, the Mine Safety and Health Administration declared the mine "gassy". While methane appeared only spasmodically and at low levels, mine redesign work had to be done, ventilation had to be increased, and permissible equipment is now required underground.

In addition to the shale oil recovered from the underground burns, Rio Blanco plans to surface retort the material brought to the surface prior to rubbleing. Rio Blanco has an agreement with the Lurgi Company for the potential construction of a 4,400 ton demonstration retort adjacent to Tract C-a. The C-E Lummus Company has the contract for the design engineering work. Construction could start in the spring of 1981. It could be on stream by 1983.

Future plans include completion of the demonstration phase by the end of 1981 so the feasibility of modified in situ technology can be assessed. In the meantime, commercial planning for the open pit approach is underway so that

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both options can be reviewed. Commercial production of 50,000 barrels per day or more could be reached as early as 1987 by either development plan.

Rio Blanco is developing a first generation technology in a closely regulated and politically sensitive environment. With the growing realization of the importance of domestic oil at all levels of government, it is likely that development of oil shale will occur and that Rio Blanco will be one of the first projects to reach commercialization.

OIL SHALE DEVELOPMENT IN MOROCCO:
A TECHNOLOGICAL AND ECONOMIC ANALYSIS USING THE OXY PROCESS

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EXTENDED ABSTRACT

INTRODUCTION

Occidental Oil Shale and its partner, Tenneco Shale Oil Company, are engaged in construction of the first commercial oil shale facility in the United States. Construction began in 1978 with the sinking of three large-diameter shafts. Commercial production is scheduled to begin in 1985 and build up to 55,000 B/D of crude shale oil, using Occidental's modified in situ process. This process has been under development since 1972 at Occidental's Logan Wash test site in northwestern Colorado. Approximately 100,000 barrels of shale oil have been produced to date from in situ retorts, three of which were approximately of commercial size. Construction is underway on two additional large-scale retorts.

This paper deals with the application of the same Occidental in situ technology to the oil shale deposit at Timahdit in the Kingdom of Morocco.

The Occidental Process - The Occidental in situ process is a radical departure from the traditional concept of mining and retorting of mined shale above ground. Instead, the oil shale is broken by conventional explosives below ground, and the broken rock or "rubble" is retorted in place. The process consists of three basic steps:

1. Driving drifts to the area of retort construction.
2. Forming the in situ retort by mining out 20 to 30 percent of the oil shale deposit and expanding the remaining shale into the mined-out volume.
3. Retorting the rubblized shale in place.

Certain features of the process are particularly important to its application in Morocco.

1. The process is site specific and operates best on thick seams of oil shale.
2. The process gives high resource recovery.
3. The process minimizes ore handling.
4. The process uses little water.

PROCESS APPLICATION IN MOROCCO

The Kingdom of Morocco, through its Bureau de Recherches et de Participations Minières (BRPM), contracted with Occidental in 1979 for a technical and economic analysis of the application of the Oxy process to its Timahdit oil shale deposit. The subsequent analyses and field test programs evaluated the ore deposit from the standpoints of geology and reserves, mine design and stability, rubblization and processing heat and material balances. The results were compared to the Colorado oil shale and a commercial design prepared for a cost evaluation now underway.

Timahdit Geology- The Timahdit oil shale deposit is part of the El Koubbat syncline and dips about six degrees from the outcrop to the syncline axis. Overburden increases from the outcrop to approximately 600 meters. The oil shale has a thickness of 250 to 300 meters, but much of this is very low grade ore (<10 gpt). A zone of 100 meters averaging about 17 gallons per ton was determined to be best suitable for the Oxy process. Total proven and probable reserves were extended as a result of the test program and are estimated to exceed 11 billion barrels of shale oil in place.

Mine Design and Stability- Laboratory and field tests determined that the Timahdit oil shale has lower strength than comparable grade Colorado oil shale. A mine design was developed to avoid the lowest strength zones. Roof deflection measurements were made in a mined-out room of the approximate size planned commercially. This room was in the planned commercial mining zone. The results were used to evaluate other expected mine openings and to develop a mine design with a large safety factor.

Rubblization- Twenty-five rubblization tests were conducted at Timahdit using single and multiple drill holes in three ore zones within the deposit. The largest tests were 1/4 scale compared to the commercial design blasts. The results were evaluated by a variety of techniques including high-speed photography for burden velocity, seismic measurements, particle size determinations and by mining into the resultant rubble. Most of the data collected compared well to comparable Colorado tests.

Processing- The Moroccan oil shale was retorted in a small pilot plant and found to give oil yields similar to those obtained on the same grade Colorado oil shale. However, Moroccan oil shale retorts at a much higher temperature. The off gas is suitable for combustion for power generation. The gas quantity and heating value are greater than for Colorado oil shale with the result that a 50,000 B/D facility could produce as much as 650 MW of surplus electrical power.

SUMMARY

The field and laboratory tests conducted on the Timahdit oil shale show the deposit suitable for development by the Oxy process. The next step is to complete the cost evaluation presently underway and to proceed to a demonstration phase in the Kingdom of Morocco.

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SESSION 6E

OIL SHALE AND OIL SANDS AND HEAVY OIL
(Panel Discussion)

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SESSION 1F

EARTH SHELTERED STRUCTURES

ABSTRACT

HISTORICAL PASSIVE EXAMPLES OF SUN FACING HILLTOWNS, CLIFF
DWELLINGS AND UNDERGROUND VILLAGES OF THE MEDITERRANEAN

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During Spring, 1980, Richard Kennedy designer/builder at Sun Space and Dr. Robert Cole, Professor at University of North Carolina at Asheville conducted a one month research expedition in Tunisia. Nineteen volunteers, through the support of EARTHWATCH, Belmont, Mass., provided assistance in studying passive energy comparisons of underground houses of the Roman Town of Bulla Reggia and Matmata and similar Berber villages in Tunisia. Besides accurate solar measurements, temperature readings, compass orientations, and room measurements, surprising results were obtained on unique natural lighting techniques, ventilation systems, earth shelter construction methods, cooling concepts, and domestic water collection.

Following this research program, Richard Kennedy documented numerous sunfacing hilltowns, cliff dwellings, and underground villages in Italy, France, and Spain. Observations ranging from window, shutter, and vent details, vegetation for climate control, and concepts for climatically responsive town planning, to name a few, will enhance our passive energy conceptual framework. This work is a small beginning towards expanding our passive energy context beyond the computer studies, new house monitoring, and design concepts of the present to actively include the wealth of useful knowledge and time proven techniques of the past.

THE FUTURE POTENTIAL OF EARTH SHELTERED STRUCTURES:
COST, ACCEPTABILITY AND PLANNING CONSIDERATIONS

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EXTENDED ABSTRACT

INTRODUCTION

Earth-sheltered structures are receiving increasing attention as a means of attacking energy and environmental problems simultaneously. The potential benefits are fairly readily understood but questions are usually quickly raised as to the cost of underground construction and the acceptability of earth-sheltered buildings as places to work and live. Also of concern is how these structures fit into existing building codes, land use plans and other institutional constraints. This paper examines these concerns and illustrates the current level of acceptability.

Cost considerations are often paramount in decisions about which type of building form to utilize. Commercial enterprises usually require a 2-3 year payback on any capital costs incurred to produce savings in operating costs. House buyers also generally require short paybacks (in the 5-7 year range) before large numbers of buyers will pay any additional cost. With these problems in mind, it is not sufficient to show a reduced life-cycle cost over an extended lifetime of the structure. The initial cost must be very competitive with conventional structures for widespread adoption of this type of building. In commercial and institutional buildings the costs for earth-sheltered buildings to date have fluctuated widely. Earth-sheltered structures forced to be on poor sites have been much more expensive than conventional buildings although in these cases an underground solution has usually been adopted for overwhelming planning reasons. On more favorable sites the cost of large earth-sheltered buildings has been in the range of between 5 percent cheaper and 10 percent more expensive than conventional. For houses, earth-sheltered construction is most frequently competitive when firms specializing in earth-sheltered housing and utilizing a number of stock plans are involved. Individual designs put out to bid in an uncompetitive market have received extremely high bids. Owner-builders are often able to build a house at low cost but this is not repeatable for potential owners without the necessary skills. There does appear to be a promise of earth-sheltered structures cheaper than conventional housing by designing for maximum soil-structure interaction such as in curved arches and shells.

The question of shell structures raises the larger question of acceptability of earth-sheltered housing in the marketplace. Shell and dome

structures have not been readily accepted by the house buying public in the past and earth-sheltered or "underground" housing at first sight would appear to have more acceptance problems. In fact, though, earth-sheltered houses seem well accepted once a person has viewed a well-designed example. It remains to be seen whether a cheaper earth-sheltered shell structure will be more or less acceptable than a more expensive but more conventional rectangular plan. The acceptability of large-scale buildings comes down primarily to a real or perceived need for windows in an office environment. The majority of office workers would prefer to have a window than not although this can be ameliorated by natural lighting techniques. There appears to be more reaction to being asked to work in a specially designed "underground" building than working in similar conditions in the interior or basement of a large building.

Planning and administrative bodies such as code and zoning authorities appear to have mixed reactions to earth-sheltered structures. Most have apparently seen planning benefits, particularly for large-scale structures and have not presented any roadblocks to construction. Others, particularly in the case of housing, have been reluctant to allow construction. Primary concerns for large buildings are fire safety for its occupants and the ability to fight fires in an underground building. Primary concerns for houses are fire safety again and neighborhood integration.

Earth-sheltered structures appear on a threshold. There is a large national interest and rapidly increasing construction activity but sound data on performance, costs and problems are still hard to obtain. The early earth-sheltered structures were carefully designed and well constructed. If it is possible to keep water penetration problems and other construction defects to a very low percentage while keeping costs fairly competitive, there seems little doubt that the numbers of such structures will continue to grow rapidly. The residential sector has had the highest growth rate to date but there is also a large potential growth in non-residential structures for the many uses which are appropriate to an earth-sheltered location.

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THE ENERGY AND ENVIRONMENTAL
RATIONALE FOR EARTH-SHELTERED STRUCTURES

by

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ABSTRACT

Earth-sheltered and underground structures offer a real and significant opportunity for saving energy; preserving valuable land resources, improving the environment and reducing building costs.

This paper presents an overview of the earth-sheltered structures with comparisons of the total energy used in an earth-sheltered residence, and a conventional, a well insulated and a super insulated above ground residence.

EXPLOITATION OF GROUND CLIMATE FOR ENERGY EFFICIENT BUILDING DESIGN

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The climate of the ground behaves very differently than that of the surface. Both daily and annual surface temperature fluctuations are equalized and undergo an approximately linear time lag as a function of depth. As a result, the subsurface environment offers a moderated thermal climate which is displaced out of phase with that of the surface. These phenomena make sod roofs, subsurface placement and berming (earth sheltering), and earth pipe heat exchangers attractive climate-tempering devices in many regions of the world.

The suitability of earth tempering strategies can only be gauged by comparing the amenities and disadvantages of both surface and subsurface climates. A model is described whereby temperature cycles at any depth in the earth can be simulated, and with which the average temperature of any specified subgrade profile can be computed. Juxtaposition of simulated earth temperatures with simultaneous air temperature normal means and extremes enables the investigator to assess the relative cooling or heating merit of earth pipes and earth sheltering practices. Juxtaposition of simultaneous temperature data also enables one to identify likely condensation problems.

The value of specific earth tempering practices must be considered in the context of the most appropriate above surface design strategies. Givoni's "Building Bioclimatic Chart" is introduced as a reference method for discussion. Atmospheric data are analyzed by Givoni's method for four cities in the United States which are generally representative of hot-humid, hot-arid, temperate, and cold climates (Miami, Phoenix, New York, Minneapolis). Synthesized ground temperatures are presented for each of these regions. It is concluded that earth tempering can reduce heating and cooling demands in many parts of the world, but that a strong emphasis on the design of such devices is necessary to make best use of both above and below ground climatic amenities.

HABITABILITY AND ENERGY PERFORMANCE OF EARTH SHELTERED DWELLINGS

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EXTENDED ABSTRACT

CONTEXT

The High Plains region of the central United States has become host to an emerging dwelling concept which incorporates the use of earth shelter technologies. Traditionally, inhabitants of this region have been sensitized to the need for windstorm protection. More recently, dramatic potentials for energy savings have served as a strong secondary inducement to the exploration of earth sheltered housing as an energy alternative.

Habitability and passive energy design are key focal elements being investigated at Oklahoma State University. Habitability aspects have received little treatment elsewhere, and existing passive energy design strategies have generally not considered the passive cooling benefits of earth sheltered construction.

In July 1979, the Office of the President at Oklahoma State University awarded a Presidential Challenge Grant to an interdisciplinary study group to assess earth sheltered housing in Oklahoma (1). The study team has since been organized into the Center for Natural Energy Design which has obtained funding from Control Data Corporation in Minneapolis to extend and expand initial research efforts. In April 1980, Oklahoma State University hosted a National Technical Conference on Earth Shelter Design Innovations, co-sponsored by the U.S. Department of Energy, to address the state-of-the-art (2).

SURVEY FINDINGS

Extended questionnaires were used to obtain earth sheltered occupant responses to both habitability and energy design aspects including measured energy usage. Preliminary analysis has been completed on about 80 (eighty) projects in the State of Oklahoma, and the study is being extended to 8 (eight) additional surrounding states. Initial results indicate that occupants are generally satisfied with such attributes as structural safety, thermal comfort and acoustical environment, but have some reservations concerning daylighting, site design, and energy design and performance. Table 1 presents an ordered ranking of respondents' assessments concerning eight habitability parameters. Assessment ratings were based on a 1 to 5 point continuum with a score of 1 indicating a low rating, and 5 a high rating.

TABLE I
MEAN CUMULATIVE RATINGS OF HABITABILITY PARAMETERS

<u>Habitability Issue</u>	<u>Rating of Respondents' Earth Sheltered Home</u>
Cumulative Thermal Scores	3.75
Cumulative Acoustical Scores	3.71
Cumulative Spatial Scores	3.69
Cumulative Maintenance Reduction Scores	3.46
Cumulative Community Setting Scores	3.41
Cumulative Lighting Scores	3.41
Cumulative Site Scores	3.11
Cumulative Lifestyle Modification Scores	2.63

ENERGY COMPARISONS

Energy usage patterns tend to indicate that, in fact, sizeable savings are being realized by owners of current generation earth shelters (3). However, it is anticipated that with optimized passive systems design, the presently realized savings could be further increased by perhaps a factor of two. An appropriate design balance must be realized between passive heating and passive cooling needs. A comparison of winter and summer thermal design loads for four potential conservation strategies as applied to five typical earth sheltered dwelling concepts is shown in Figure 1.

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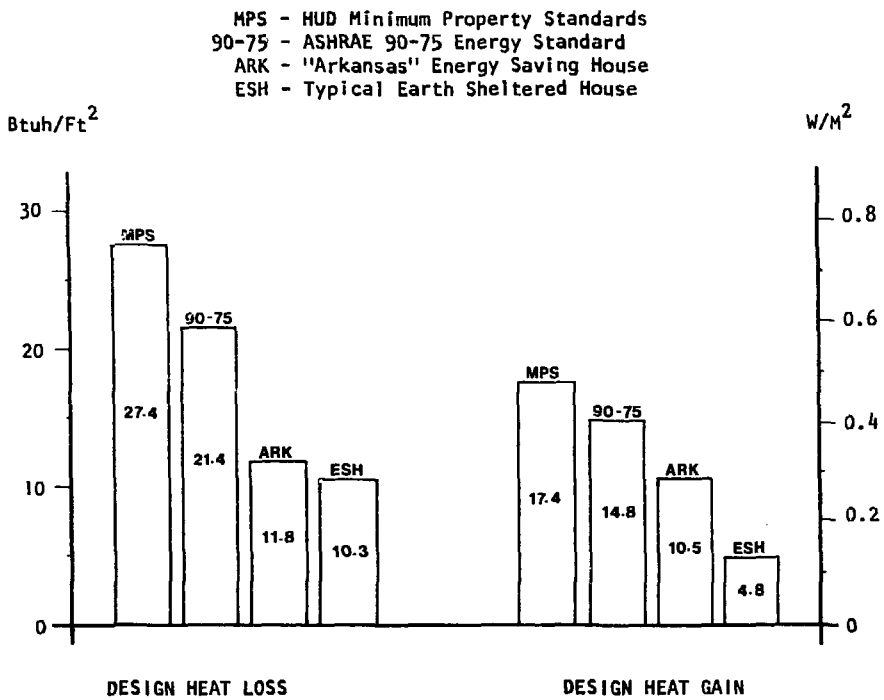


Figure 1. Comparison of Average Design Loads

PROPOSED PRINCETON ENERGY RECYCLING CENTER

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ABSTRACT

Princeton, New Jersey, a town of 30,000 people is in a unique position to utilize solid waste and sewage sludge as supplementary energy sources. The Stony Brook Sewage Authority recently constructed a new twenty million dollar sewage treatment plant next to the old sewage treatment plant which served the community of Princeton for forty years. On the site of the old plant is an abandoned incinerator plant which presently is being used as a transfer station.

The new sewage treatment plant is disposing its sludge by burning it in multiple hearth furnaces using sixty gallons of precious oil to do this.

The proposed Princeton Energy Recycling Center is designed to be retrofitted with solar sludge dryers to dry the sewage sludge which would be transported by conveyer to the old incinerator plant where it would be mixed with garbage and be burned in rehabilitated furnaces which would be retrofitted for steam generators, a steam engine driven electric generator and air pollution control equipment.

It is estimated that the proposed energy recycling center would fulfill all electrical needs of the new sewage treatment plant in addition to solving the solid waste and sludge disposal problems of the Princeton community.

The paper presents a detailed discussion on the proposed Princeton Energy Recycling Center.

ECONOMIC ANALYSIS OF SOLID WASTE-TO-ENERGY PLANTS
FOR SMALL COMMUNITIES

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The objective of this study was the determination of the economic feasibility of energy recovery from solid waste for a five-county area of Southeastern Arkansas. Unlike most resource recovery facilities, which have been designed for large volumes of waste from municipalities, the maximum size of this plant was limited by the low population density of the region. The counties are rural in nature, with a total population of 80,000, and the total waste generation slightly greater than 200 TPD. Therefore, technologies requiring materials separation; e.g., RDF, Pyrolysis, were eliminated because of high capital costs. The two-chambered, modular combustion technology was chosen because of its lower capital cost and ability to handle raw refuse. Modular combustion units have been used extensively in Arkansas, and despite some problems with some of the earlier units, performance has been generally satisfactory. Solid waste is loaded in the first chamber, where it is burned under starved-air conditions, releasing combustible gases in a pyrolytic-type reaction. These gases are then drawn into the second chamber and completely combusted and the exhaust gases are sent to a heat exchanger. The chief advantage of this technology is low particulate emissions, and the modular design which allows additional units to be added as the waste supply increases. Steam generation efficiency is less than a waterwall incinerator (55% versus 70%), and the quality of the steam produced is lower (150 psi saturated steam), but the modular design allows the waste disposal system more flexibility in responding to the needs of potential customers. This is especially important in rural areas where there are few large industries or institutions to purchase steam from a waste-to-energy facility.

The methodology used to compare different options was life-cycle costing of each alternative. Energy costs were assumed to escalate at a rate 2% above other costs. Transportation costs and the avoidance of landfilling costs were included for each option. Three different sites, resulting in eighteen combinations of waste sources and steam customers, were analyzed in order to determine the optimal combinations. This was necessary because the long transportation distances and variety of trash generation sites meant that there were a large number of potentially viable sites. By comparing the effect each option had on the relative cost of solid waste disposal for the region, the optimal size and site for a refuse-derived energy plant was selected as part of a solid waste management system.

GENERATION OF ENERGY FROM THERMAL PROCESSING
OF MUNICIPAL SOLID WASTE IN THE UNITED STATES

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EXTENDED ABSTRACT

An in-depth study of the generation of energy from the thermal processing of municipal solid waste in the United States is presented herein. The information is based upon surveys conducted from 1975 through 1980 with the assistance and cooperation of the Solid Waste Processing Division of the American Society of Mechanical Engineers. The information contained in this paper is a significant update of material presented previously [1-6].

INTRODUCTION

Information is presented for each of the facilities in the United States from which energy from the thermal processing of solid waste is being or will be generated. A review of the operational problems encountered in the facilities that are in operation or in shakedown is presented.

ENERGY FROM THERMAL PROCESSING

Data on each of the facilities in the United States from which energy in various forms is being or will be generated is presented in tabular format. A brief description of the problems encountered and the current status of the plant is given for each facility. The plants are broken down into the following four categories:

- (1) Facilities producing refuse derived fuels
- (2) Mass burning facilities with waterwall furnaces
- (3) Mass burning with waste heat recovery
- (4) Facilities producing fuel and energy from pyrolysis methods

Facilities Producing Refuse Derived Fuels Each of the twenty-five (25) facilities which are in final contracts, construction, shakedown or operation which produce refuse derived fuel (RDF) for later use in a thermal process to produce energy are discussed.

Mass Burning Facilities with Waterwall Furnaces Each of the eleven thermal processing plants utilizing waterwall furnaces for combustion of the municipal solid waste to produce energy in the form of steam, chilled water or electrical power is discussed. It is demonstrated that this type of facility has established a history of reliable generation of energy from the thermal processing of municipal solid waste similar to the numerous facilities in Western Europe which have similar but more consistent and longer performance records.

Mass Burning With Waste Heat Recovery Each of the four facilities in which waste heat recovery is utilized in the incineration process is discussed including the plant at Glen Cove, N.Y. which is under construction and in which co-disposal of sewage sludge is employed.

Facilities Producing Fuel and Energy From Pyrolysis Methods The three facilities utilizing pyrolysis are discussed although two of these facilities have been closed for significant periods of time and appear unlikely to reopen.

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TABLE 1 FACILITIES IN U.S. GENERATING ENERGY FROM REFUSE

LOCATION OF FACILITY	STATUS				DESIGN CAPACITY tons/day (c/day)	PROCESSING										MATERIALS RECOVERY			
	YEAR-INITIAL	OPERATIONAL	SHUTDOWN	CONSTRUCTION		NO. PROCESS LINES	WYTH SLUDGE	SUSPENSION	COARSE SEPARATION	FAC. SEPARATION	2nd SHREDDING	2nd AIR CLASSIFY	PERIODS	GLASS	ALUMINUM	NON-FERROUS	MIXED METALS	ENERGY USAGE	
FACILITIES PRODUCING REFUSE DERIVED FUELS (RDF)																			
AKRON, OH	1979*	x			907(1000)	2	x	x	x	x	x	x	x	x	x	x	x	x	S-I
ALBANY, NY	1980*		x		680(750)	2	x	x	x	x	x	x	x	x	x	x	x	x	S
AMES, IA	1975	x			131(200)	1	x	x	x	x	x	x	x	x	x	x	x	x	S
BALTIMORE CO., MD	1976	x			907(1000)	2	x	x	x	x	x	x	x	x	x	x	x	x	S
BRIDGEPORT, CT	1979		x		1633(1300)	2	x	x	x	x	x	x	x	x	x	x	x	x	S
CHICAGO (SW. SUPP.), IL	1979	x			907(1000)	2	x	x	x	x	x	x	x	x	x	x	x	x	S
COLUMBUS, OH	1982*			x	1814(2000)	2	x	x	x	x	x	x	x	x	x	x	x	x	S
DADE CO., FL	1981*				2722(3000)	2		x	x	x	x	x	x	x	x	x	x	x	S
DETROIT, MI	1981*		x		2722(3000)	3	x	x	x	x	x	x	x	x	x	x	x	x	S-I
DULUTH, MN	1979*	x			363(400)	2F	x	x	x	x	x	x	x	x	x	x	x	x	S
EAST BRIDGEWATER, MA	1973				454(500)	1	x	x	x	x	x	x	x	x	x	x	x	x	S
HEMPSTEAD (BC), NY	1978	x			1614(2000)	2	x	x	x	x	x	x	x	x	x	x	x	x	S-I
LANE CO., OR	1978	x			454(500)	1	x	x	x	x	x	x	x	x	x	x	x	x	S
MADISON, WI	1979	x			363(400)	1	x	x	x	x	x	x	x	x	x	x	x	x	S
MILWAUKEE, WI	1977	x			1451(1600)	2	x	x	x	x	x	x	x	x	x	x	x	x	S
MENROE CO., NY	1981*				1814(2000)	2	x	x	x	x	x	x	x	x	x	x	x	x	S
NEWARK, NJ	1981*		x		2722(3000)	3	x	x	x	x	x	x	x	x	x	x	x	x	S
NEW CASTLE CO., DE	1973	x			907(1000)	2	x	x	x	x	x	x	x	x	x	x	x	x	S
NEW ORLEANS, LA	1978	x			590(650)	2	x	x	x	x	x	x	x	x	x	x	x	x	S
NILAGARA FALLS, NY	1981*		x		1996(2200)	3	x	x	x	x	x	x	x	x	x	x	x	x	S
OGDEN (WEBER CO.), UT	1982*		x		544(600)	2	x	x	x	x	x	x	x	x	x	x	x	x	S
POMPANO BEACH, FL	1973	x			91(100)	1A	x	x	x	x	x	x	x	x	x	x	x	x	S-I
ROCHESTER (KODAK), NY	1970	x			163(180)	1	x	x	x	x	x	x	x	x	x	x	x	x	S
TACOMA, WA	1978	x			454(500)	1	x	x	x	x	x	x	x	x	x	x	x	x	S
WILMINGTON, DE	1982	x			907(1000)	1	x	x	x	x	x	x	x	x	x	x	x	x	S
23 17801513127561(30180) 141																			
FACILITIES PRODUCING FUEL AND ENERGY FROM PYROLYSIS METHODS																			
BALTIMORE (LANG), MD	1973	x			907(1000)	2		x	x	x	x	x	x	x	x	x	x	x	S
SAN DIEGO CO., CA	1977C	x			181(200)	1		x	x	x	x	x	x	x	x	x	x	x	S
SOUTH CHARLESTON, WV	1974C	x			181(200)	1		x	x	x	x	x	x	x	x	x	x	x	S
3 213101011269113001 101																			
MASS BURNING FACILITIES WITH WATERWALL FURNACES																			
BRAINTREE, MA	1971	x			218(240)	2R													S
CHICAGO (NM), IL	1971	x			1451(1600)	4M													S-I
HAMPTON, VA	1980*		x		181(200)	2D													S
HARRISBURG, PA	1972	x			653(720)	2M													S
NASHVILLE, TN	1974	x			962(1068)	2D													S
NORFOLK (NAVY), VA	1967	x			327(360)	2D													S-I
OCEANSIDE, NY	1965	x			680(750)	3E													S
PINELLAS CO., FL	1982*		x		1814(2000)	2													S
PORTSMOUTH (NAVY), VA	1976	x			145(160)	2D													S-I
SAUGUS (RESCOR), MA	1975	x			1099(1200)	2M													S-I
10 31111111111111111111 101																			
MASS BURNING FACILITIES WITH WASTE HEAT RECOVERY																			
GLEN COVE, NY	1981*		x		204(225)	2	x												S
MERRICK, NY	1952	x			544(600)	4													S
NEW YORK (BETTES), NY	1948	x			907(1000)	2													S
ROCKFORD, IL	1971	x			318(350)	2D													S-I
1 31111111111111111111 101																			
TOTAL 42 17801513127561(30180) 141																			

SIMULATING CRITERION FOR BIO-CHEMICAL CONVERSION OF REFUSE TO SYNTHETIC
FUEL AND ELECTRIC POWER

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INTRODUCTION

This paper presents through the mechanism of simulation significant performance results describing the operational criterion of synthetic fuel production and then the process of bio-electrochemical energy conversion.

Generation of electric energy from refuse through the process of bio-conversion is performed by the bio-electro-chemical fuel cell. The bio-organic matter is prepared from refuse and then injected as fuel to the Anode, pre-heated air as an oxidizer to the Cathode, where both are coupled through an organic electrolyte such as potassium hydroxide.

Resorting to the criterion that useful electric energy output from the bio-electro-chemical fuel cell is the transformed product secured from the interaction of the local reactants with the material environment coupled with the criteria of total continuity of the cell fluids, reliable results have been developed through systematic simulation describing the bio-chemical local kinetics and dynamics, thermal effects, electric field generated by electro-chemical energy transformation as well as local entropy and enthalpy within the cell continuum. The same principle of local reactants-material environment interaction and the continuity equations have been used successfully in the development of system models simulating the kinetic as well as the dynamic characteristics for the pure bio-chemical process of synthetic fuel extraction from organic refuse. The process of bio-chemical conversion takes place with a prepared refuse that will be digested with anaerobic bacteria, producing multigrades of un-saturated as well as saturated hydrocarbon of the order of C_nH_{2n+2} (n is the grade of the hydrocarbon).

From the preceding analysis, mathematical simulation in the form of coupled partial differential equations associated with variable coefficients in the time domain, followed by total dynamic model in the state variables domain have been established for the over-all bio-electro-chemical energy extraction from synthetic fuel, as well as for the bio-chemical conversion of organic wastes to synthetic fuel.

From the above-mentioned simulating mathematical as well as dynamic models developed, useful information has been obtained defining several operational criteria for optimum performance of bio-conversion of organic refuse to synthetic fuel and then eventually to useful electric energy in terms of equivalent bio-electrochemical potential of reactants, order of hydrocarbons, and their concentrations, as well as

local conditions of entropy and enthalpy. Stability aspects concluded from the dynamic models, identified reliable spectrum of fluctuation for the electric terminal voltage and or electric field intensity in terms of cell operational parameters. Transform solution in the complex frequency domain is expressed below for the cell fluid continuum concentration with respect to average flow velocity:

$$\frac{n_i(S)}{v_i(S)} = \frac{\frac{3S}{Y_i} \sum_{k=1}^p \frac{A_i(S_k)}{B_i(S_k)} n_i(S-S_k)}{\frac{Y_i}{2S^2} - \frac{1}{2} \sum_{k=1}^p \frac{M(S_k)}{N'(S_k)} v_i(S-S_k)} \quad (1)$$

where

Y_i = sum of (sources - sinks)

S_k = kth order pole

n, v = concentration and flow velocity.

Steady state solution for the cell electric field intensity with constant entropy is written below:

$$e = \frac{n_i + N_i}{Mn_i} \quad (2)$$

e = electric field intensity in the cell continuum

n_i = concentration of ith reaction process

N_i = discrete electro-chemical reaction order

While in the absence of spatial gradients, e is expressed as:

$$e = -\frac{B}{2A} \pm \sqrt{B^2 - 4AC}$$

where

$$A = MD \frac{\partial N_i}{\partial x} - Mn_i$$

$$B = D \frac{\partial N_i}{\partial x}$$

$$C = \frac{n_i + N_i}{D} + \frac{TM}{FD} \frac{\partial Q}{\partial D}$$

D = the cell continuum width

M = electric field mobility

Q = entropy

Generalized solution of $e(x,t)$ is also secured in terms of thermodynamic and electro-chemical parameters of the bio-cell.

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GAS PRODUCTION FROM SANITARY LANDFILLS
AS A POTENTIAL ENERGY RESOURCE

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EXTENDED ABSTRACT

INTRODUCTION

The rapid escalation of energy prices causes the potential of landfill gas as a source of energy to be recognized. Municipal solid waste disposal sites are considered untapped sources of methane gas. Landfill gas, which is mainly produced during anaerobic decomposition, primarily methane and carbon dioxide, has a volume composition of 40 to 60 percent methane (1,2,3). If methane is not recovered and utilized it migrates through the adjacent soils and becomes an explosive mixture with oxygen in concentrations ranging from 5 to 15 percent by volume methane, and poses major explosion hazards in facilities located near sanitary landfills (4,5,6). plus other environmental effects such as damage or death to vegetations (8), odors, asphyxiation and injury to health, groundwater contamination due to the presence of carbon dioxide (9), and a possible reduction in the ozon shield layer (10). Other gases produced in Sanitary Landfills are nitrogen, ammonia, and hydrogen sulfide.

RECOVERY AND UTILIZATION OF LANDFILL GAS

The amount of recoverable gas depends upon two factors: the ultimate gas production and the area depth relationships. The second factor affects air infiltration, a deeper landfill is preferred to a shallow landfill, even though volume is constant. If air infiltrates into the landfill, methane production will cause or decline to a level where the methane content of the raw gas is too low for economic recovery.

Methane gas production is the deciding factor in considering methane as an alternate energy resource and is investigated

in this study. A pattern of sanitary landfill gas production and factors affecting it such as moisture content, temperature, pH, alkalinity, and nutrition are also discussed in the full length text.

CONCLUSIONS

It is found that, in general, the principles developed from gas production in other media are applicable to the landfill environment. It is found that gas production increases with increased moisture content but that conditions of high infiltration are often conducive to reduction in gas production apparently caused by modifications to the microbial environment. Gas production proceeds over a wide range of temperatures with maximum production rates occurring at 30°C to 35°C. Optimum levels of PH and alkalinity exist which maximize gas production rates. The types and amounts of gas produced are influenced by refuse composition.

Finally, cost estimates for collection and treatment, indicates that landfill gas, while not presently competitive with natural gas or oil, is competitive with LNG or SNG. Thus, landfill gas can be an important supplemental of alternative fuel source.

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EMPLOYMENT OF A REFUSE DERIVED FUEL
(RDF) IN LOW POWER THERMAL PLANTS

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3rd. Miami Intern. Conf. on Altern. Energy Sources

One of the new energy sources under experimentation are the municipal solid wastes, from which it's possible to recover a refuse derived fuel (r.d.f.) suitable to be burnt in electric power facilities, cement kilns and other thermal plants.

The contribution of these fuels, together with mass combustion, commonly gets in the developed countries 1 ÷ 2% of the total energy demand.

Aim of our work is the evaluation of the energetic characteristics of the new r.d.f.s, their employment in small thermal units and the environmental impact of their combustion emissions.

The used r.d.f. was the one produced in Rome, where two recycling plants (600t/d and 1200 ton/d), may be the first ones in the world, have been running since 1970.

This fluffy fuel is not, as in the most part of the plants in the States, the main product of the selection lines but it is a secondary by product.

As a matter of fact the facilities in Rome can recover, in addition to iron and glass, paper plastics and the organic fraction (50% of entered refuse) which is transformed into animal feed and compost.

The characteristics of the italian rdf, named calurb, are the following:

composition %		ultimate analysis %	
paper	38,5	C	55
plastics	38,7	H	8,5
textiles	20	Fl	0,033
wood	0,3	Cl	0,69
inherents &		N	0,71
mix inorg.	3,5	S	0,2
humidity at 105°C (221°F) 4,1%		lower heat value 24650 kJ/kg (51700 BTU/lb)	
organic fraction at 600°C (1112°F) 93,1%		ashes at 1000°C (1832°F)	

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The plant used for the combustion experiments is illustrated in fig. 1. It consists of a marine boiler, a conventional burner suitably modified, a pneumatic transport system for the r.d.f., a primary air fan, and a gas oil pump. It is connected with the boiler testing station in our Institute, which operates according to the enthalpy balance method. The core of the burner consists of an almost usual gas oil combustor to which the rdf is pneumatically fed. Then, the fuel flows into the gas oil combustion zone, because of the higher transport air pressure.

Another of the purposes of this research is to demonstrate that it is possible to utilize a rdf in a nearly conventional small burner. The power of our plant is 250 kW (870.000 BTU/h), whose 75% at the most can consist of rdf.

The quantities we measured in addition to the ones needed for the enthalpy balances are: flue gases and combustion chamber temperatures, dynamic and static pressures and flow rates of the combustion and transport air, chemical composition (analysis) of the gases referred to CO_2 , O_2 , Cl , HCl , SO_2 , NO , H_2O , SPM ashes quantity and their chemical composition. We plotted the efficiency of the boiler as a function of the total power input, of the fuels ratio (rdf v. gas oil) and of the rdf power input versus the total p.i.

At low rdf/gas oil ratios we had the highest efficiency values. From our first results it seems that the total power input does not really affect our boiler performances. Fig. 2 shows the curve efficiency/rdf power percentage.

We could come to the conclusion that, at lowest rates rdf improves the boiler efficiency showing two advantages: to spare energy and to use a recovered form of energy (the rdf).

We are going to furtherly verify these results and to experiment a new pre-boiler combustion chamber able to grant, in spite of its short dimensions, high temperature, turbulence and dwell time long enough for the complete combustion of the rdf.

Acknowledgements

This paper describes the first results we got under the 3 years research, contract n° 78.01183.92 with our National Research Council-Energy Project developed in cooperation with the company Sorain Cecchini in Rome. We are sincerely grateful to dott. ing. Carlo Noto La Diega and dott. ing. Paolo Magnani for the precious cooperation and for all the data or rdf used.

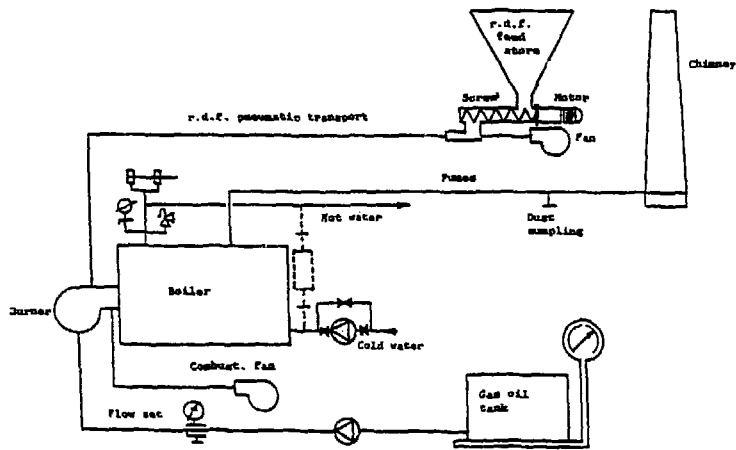


Fig. 1 PILOT PLANT SKETCH

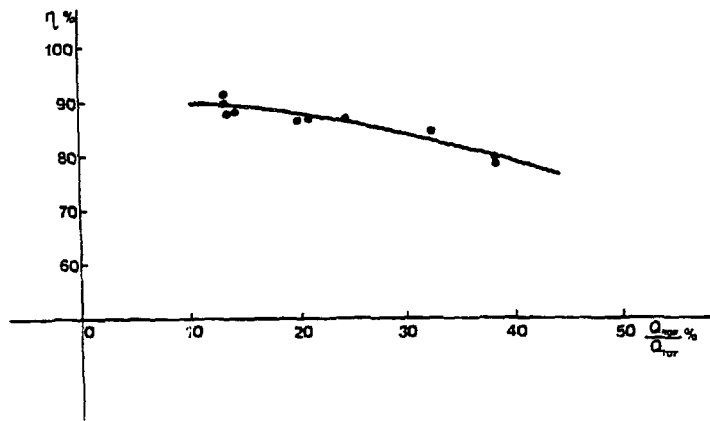


Fig. 2 RELATIONSHIPS BETWEEN EFFICIENCY AND A.D.P. ADMITTED POWER AND TOTAL POWER RATIO

FUEL CELL COGENERATION USING ANAEROBIC DIGESTER GAS

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The U.S. Department of Energy has undertaken several conceptual design studies to determine the technical and economic feasibility of utilizing fuel cell power plants for industrial cogeneration applications. The objective of this effort was to establish the practicality of pursuing a phased engineering program, similar to that already in progress for an electric utility application, culminating in a fuel cell power plant cogeneration demonstration.

One of these studies [1] addressed the integration of fuel cell power generation with a large water pollution control facility and electrical grid system. The study, under the direction of Gilbert/Commonwealth, specifically focused on application of the United Technologies Corporation (UTC) 4.5 MWe Utility (fuel cell) Demonstrator Power Plant to the Bergen County Utilities Authority (BCUA) water pollution control facility located in Little Ferry, New Jersey, in the service territory of Public Service Electric and Gas Company (PSE&G).

Methane-rich gas from the anaerobic digestion of raw sewage provides a fuel feedstock for the fuel cell power plant. In turn, heat rejected from the fuel cell power plant is used to sustain high levels of bacterial action in the digesters (which have an optimum operating temperature of 95°F) and satisfy other facility heat requirements. The electrical output of the fuel cell power plant is fed to the PSE&G power grid serving the BCUA facility. (See Figure 1.)

Several design configurations were evaluated. These configurations were comprised of combinations of options for locating the fuel cell power plant at the site, electrically connecting it with the water pollution control facility, using the rejected power plant heat, supplying fuel to the power plant, and ownership and operation.

A configuration was selected which met institutional/regulatory constraints and provided a net cost savings to the industry and the electric utility. The displacement of oil and coal resulting from the BCUA application was determined.

Specific study results showed that the UTC 4.5 MWe Utility Demonstration Power Plant is operationally compatible with the BCUA water pollution control facility. No institutional or regulatory constraints were found which would prohibit the installation or operation of the power plant. Further, the fuel cell power plant could deliver electric energy (30×10^6 kWh/yr) equivalent to about half the annual needs of the water pollution control facility and provide over ninety percent (approximately 70×10^9 Btu) of its annual thermal energy requirements while using all of the facility's digester gas. Sixty-five percent of the total energy content of the digester gas is used to produce this electrical and thermal energy. This is

accomplished with essentially no changes to the 4.5 MWe Utility Demonstrator Power Plant's present design or operating characteristics.

A detailed economic comparison was conducted which indicated the cost savings to be realized if the cogeneration fuel cell power plant was used in place of the conventional means of supplying electrical and thermal energy to the facility. (See Figures 2 and 3.)

For example, if the cost of the UTC supplied fuel cell power plant equipment were \$650/kW (uninstalled, in 1982 dollars, \$535/kW in 1979 dollars), a total levelized savings of \$589,000 per year (1982 dollars) could be realized. Uninstalled break-even capital costs for the fuel cell power plant equipment are \$1258/kW (1979 dollars) or \$1488/kW (1979 dollars), depending on whether, respectively, PSE&G or BCUA owns the power plant.

In addition to these economic considerations, this specific cogenerating fuel cell power plant would displace 26,000 barrels of No. 6 fuel oil (on-peak) and 5,900 tons of coal (off-peak) each year.

Based on the favorable results of this conceptual design analysis, continuation of this project to the next phase, Preliminary Engineering Design, under the management of PSE&G was recommended.

The work described by this abstract was jointly sponsored by the Department of Energy Divisions of Conservation (SF operations), Power Systems and Industrial Energy Conservation (Germantown) under Contract DE-AC03-78ET12431.

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Figures 2 and 3 follow on next page.

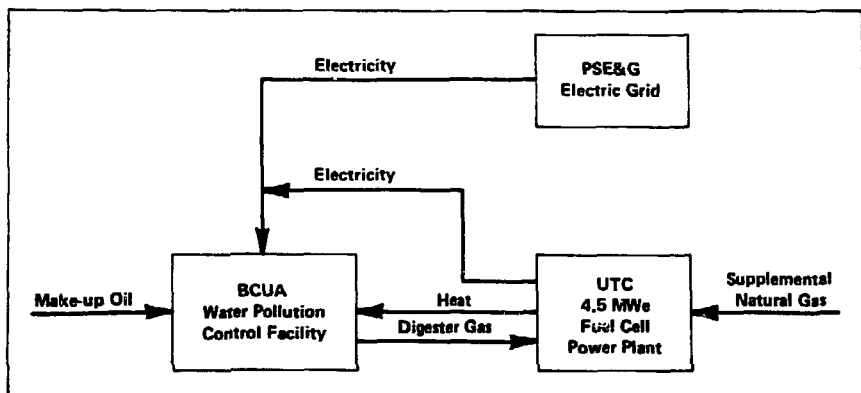


Figure 1. Fuel cell power plant cogeneration in a water pollution control facility.

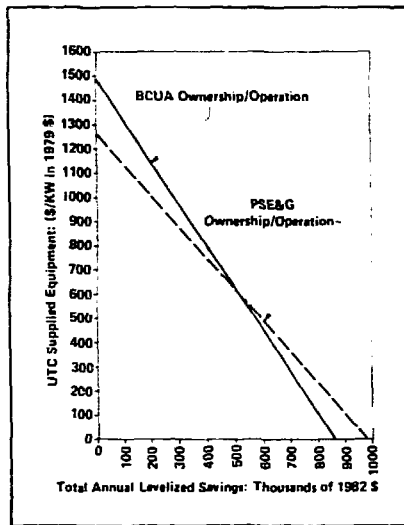


Figure 2. FCPP cogeneration project breakeven capital cost of UTC supplied equipment including dry cooling tower.

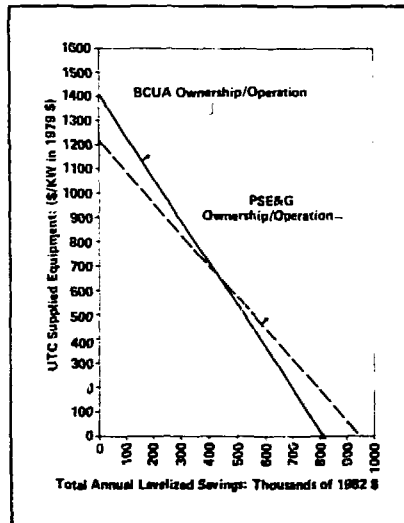


Figure 3. FCPP cogeneration project breakeven capital cost of UTC supplied equipment excluding dry cooling tower.

PROTOTYPE DEMONSTRATION STUDIES OF PRODUCTION OF
METHANE FROM MUNICIPAL SOLID WASTE AT
POMPANO BEACH, FLORIDA

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EXTENDED ABSTRACT

INTRODUCTION OF THE ANAEROBIC DIGESTER

A prototype demonstration plant for the production of methane from the anaerobic digestion of municipal solid waste in amounts up to 100 tons per day is built at Pompano Beach, Florida. The plant is capable of producing 600 ft³ of gas per ton of municipal waste. Approximately half of the gas is methane, the other half CO₂ along with some trace gases.

Anaerobic digestion of municipal solid waste is one of the recent concepts being developed to generate methane, a source of alternative energy. In this plant the raw municipal solid waste is shredded, ferrous metals removed magnetically and air classified to obtain an organic-rich light weight fraction, which is periodically mixed with sewage sludge and fed into the anaerobic digester. The processed effluent is filtered in a vacuum filter and the emerging filter cake is disposed on the nearby existing sanitary landfill. The filtrate is recirculated into the digester.

RESULTS AND DISCUSSION

The Waste Management Inc. facility is approximately 50 miles north of the University of Miami. Field trips are scheduled approximately once per week to collect and analyze gas, liquid and solid samples. So far over 30 trips have been made to collect the samples. Figure 1 gives the flow sheet of the anaerobic digestion plant, indicating different sampling sites.

Gas samples have been analyzed using eolyzers for CO and H₂S, gas chromatographs, and Finnegan GC/E'-C' mass spectrometer. Apart from the major constituents, CH₄ 42-59%, and CO₂ 34-52% the other constituents identified are CO; H₂S, ethane, propane, butane, water, non-methane hydrocarbons, vinyl chloride, trichloroethylene, tetrachloroethylene, pentane, ethylene

and ammonia. Occasional, air peaks have been identified, which could be leaks through lines. Except for CH_4 , CO_2 and H_2S all other constituents are in the parts per billion range.

All solid and liquid samples have been collected and analyzed for physical, chemical and biological parameters as recommended in Standard Methods, 14th Edition. Elemental analyses was performed on air classified light fraction to analyze for carbon, hydrogen and nitrogen on a percent dry weight basis. The nitrogen levels vary from 0.26 to 1.01 percent. Carbon levels are between 41.9 to 45.4 percent. Hydrogen levels are between 5.64 to 6.4 percent. Oxygen levels are between 46.1 to 52 percent.

Average concentrations of BOD, COD and TOC are 1073, 6855 and 1655 mg/l, respectively, in filtrate. Total nitrogen is 180 mg/l while total phosphate varies between 37 to 300 mg/l in the filtrate. These high levels of nutrients are attributed to addition of diammonium phosphate and nitrogen as nutrient to the digester. Density of fecal coliform is found to be 5.1×10^5 per 100 ml. Concentration of heavy metals is found to be far below the level of toxicity. Current plan calls for 100 percent recirculation of this filtrate, however, it is expected that occasional discharge of this filtrate will be necessitated in future to reduce the build-up of toxics in the digester.

First year of the operation of the plant was interrupted with several mechanical break downs, which have been corrected with operational experience. Last year in December there was a fire incident, resulting in roof cracks of the digester and consequently all plant was shut down for at least one month. Apart from these physical problems, process of conversion of refuse to methane gas appears to be practical at demonstration scale.

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ACKNOWLEDGEMENTS

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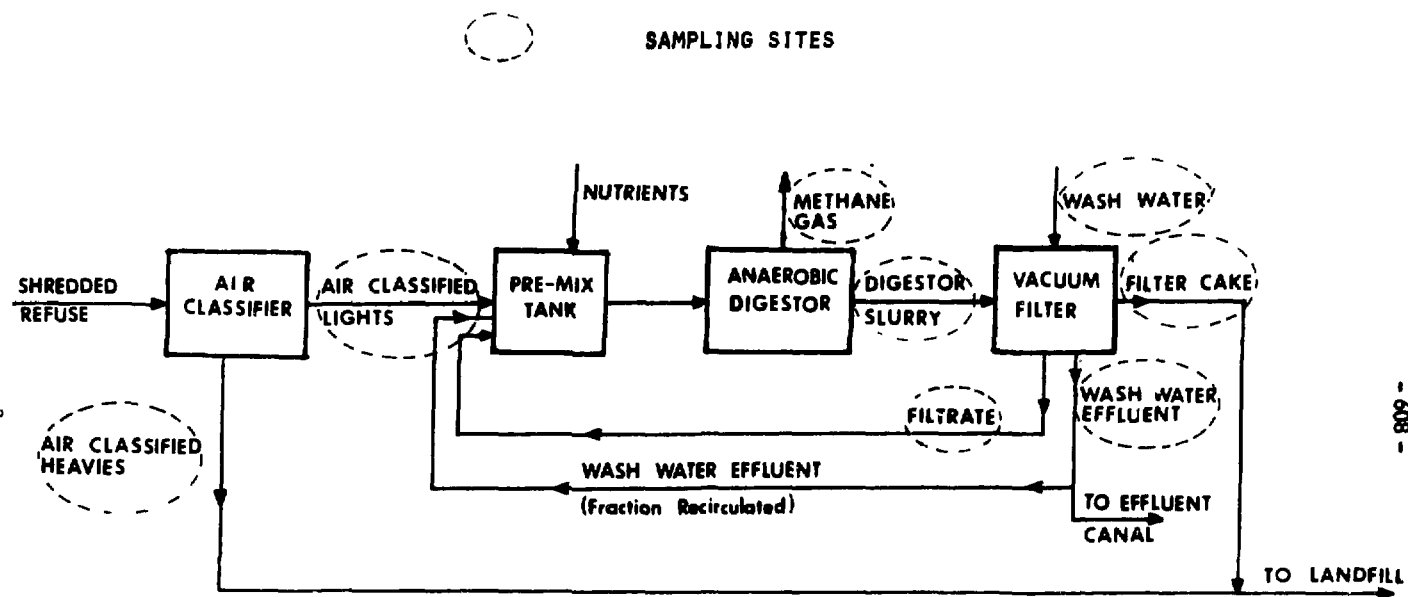


FIG.1 Flow Diagram of Anaerobic Digestion Plant

CHARACTERIZATION OF GAS PRODUCED BY THE ANAEROBIC DIGESTION OF MUNICIPAL SOLID WASTE

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EXTENDED ABSTRACT

INTRODUCTION

The feasibility of producing methane-rich gas from the anaerobic digestion of municipal solid waste is currently being evaluated at a 100-ton-per-day proof-of-concept facility operated by Waste Management Incorporated (WMI) in Pompano, Florida. The University of Miami together with the AMES Research Laboratory is participating in the environmental source assessment of that technology which is to include the identification of all contaminants that potentially could exceed specific standards, and others which may have a deleterious effect on the environment. The ultimate goal is to insure that the process products are environmentally acceptable or are of less environmental consequence (with or without controls) than if generated in an unprocessed landfill. This paper describes the gas analysis procedure and the gas composition as identified to date for unstable, lower mesophilic (30°-40°C) digester conditions with the plant operating at approximately 15 per cent of its design capacity. The reader is referred to reports by Sengupta et al [1] and [2] for a more detailed discussion of the work in progress. Results for stable mesophilic and thermophilic conditions with higher loadings must await further WMI operational programs and University of Miami testing.

SAMPLING PROCEDURE

Off-gas samples were obtained through an in-line valve located 3 feet above the ground in a vertical section of 8-inch pipeline approximately 15 feet upstream from where the gas is flared. A series of two condensers submerged in ice were used to remove the water from the saturated gas. The dried gas was then passed to a direct reading Ecolyzer where H_2S levels were monitored for periods of up to an hour on a given field trip. Grab samples were collected in thoroughly conditioned glass bulbs and Tedlar bags at the same location. New septums were used on each field trip and the grab samples were kept out of direct sunlight while in transit to Miami for analysis. The analysis were performed as soon as possible after sample acquisition.

GRAB SAMPLE ANALYSIS PROCEDURE

Grab samples were analyzed in Miami using a Hewlett-Packard 5834A Dual Thermal Conductivity Detector (TCD), Dual Flame Ionization Detector (FID) Gas Chromatograph (GC). The instrument was configured with a 12-ft Porapak Q column (1/8" stainless, 80/100 mesh) and a 6-ft Molecular Sieve 5A column. The latter with a Methanator was used to analyze CO concentrations

and N_2/O_2 ratios. The former with appropriate programming, valve changing and detector switching was used for CO_2 , CH_4 , NH_3 , and C2-C6 hydrocarbons. The columns were conditioned while on the field trips and calibrations of retention times and peak areas were made upon return from the field using certified gas mixtures. The analysis was then made using the updated response factors. Quality assurance was stressed throughout the analytical procedure. Occasional runs were made using a Finnigan Model 4000 Electron Impact (EI) / Chemical Ionization (CI) GC Mass Spectrometer (MS) to identify unknown GC peaks and sulfur constituents. A Non-Dispersive Infrared (NDIR) system was used to confirm NH_3 levels. And an Ecolyzer was used to confirm the presence of CO in the sample. We are in the process of obtaining a Flame Photometric Detector (FPD) to assist with the analysis of sulfur compounds.

COMPOSITION OF DIGESTER GAS

A composite summary of the gas quality is presented in Table 1. The National Ambient Air Quality Standards (NAAQS), [3], OSHA 8-Hr Standards, [4], and several odor threshold values [5], are also included to assist with interpreting the results.

DISCUSSION OF RESULTS

Before discussing the results, it should be mentioned that CO was not observed during the second year of digester operation and the H_2S levels appear to be lower that year also but the data were contaminated by numerous air leaks through the digester seal and more testing is needed. Moreover, the high NH_3 levels were probably related to the recent addition of sewage sludge to the system.

With that background and considering a gas leak rate of 100 cfm into environmental air with a dilution factor of 10^{-4} , we see from Table 1 that the only constituent of potential environmental concern would be H_2S because of its low odor threshold. If the digester gas is burned without cleaning, the oxidized NH_3 would produce nitrogen oxides which may or may not be of concern. It is premature at this point to render environmental impact conclusions since much more testing is needed.

COMPARISON OF RESULTS WITH OTHER STUDIES

As one would expect, the composition of the digester gas was found to be similar to that in small-scale tests [6] and in landfills [7] with the exception of H_2S and NH_3 . The landfill H_2S levels were less than 50 ppm, and the NH_3 levels were about 1 ppm. During the coming year, we will be giving special attention to trace constituents which may have evaded previous analytical efforts.

CONCLUSIONS

The quality of the methane-rich gas currently being produced at the WMI Pompano anaerobic digestion facility has been described. It must be remembered, however, that those results were for unstable lower mesophilic digester conditions with the plant only running at 15 per cent of its design capacity. Thermophilic conditions have yet to be evaluated. Moreover, the plant has not yet achieved stable operating conditions. A complete environmental assessment of this technology must await further testing.

ACKNOWLEDGEMENTS

We are grateful to DOE for sponsoring this work under contracts EV-78-S-05-6072 and DE-AS05-78 EV10133, and to Dr. Gerald Goldstein for his assistance and support as project manager. WMI personnel provided valuable assistance during our field sampling periods. Sook Rhee typed the manuscript.

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TABLE 1 Composite Summary of Gas Quality
in the Pompano Digester.

CONSTITUENT	CONCENTRATION	NAAQS ¹	OSHA ² 8-HR STD	ODOR THRESHOLD
Air	0-Few %	-	-	-
CH ₄	42.2-62.7 %	-	-	-
CO ₂	32.3-52.9 %	-	5000 ppm	-
CO	0-100 ⁺ ppm	8 Hr 9 ppm 1 Hr 35ppm	50 ppm	-
C ₂ H ₆	0-24.3 ppm	-	-	-
C ₃ H ₈	GC/MS Peak	-	1000 ppm	-
C ₄ H ₁₀	GC/MS Peak	-	-	-
C ₅ H ₁₂	GC/MS Peak	-	1000 ppm	-
C ₄ ⁺	0-77 ppm	-	N/A	N/A
H ₂ S	0-500 ⁺ ppm	-	20 ppm	.47 ppb
SO ₂	None	.03-.5 ppm	5 ppm	.47 ppm
NO ₂	None	Annual .05 ppm	5 ppm	-
NH ₃	Up to 1821 ppm	-	50 ppm	46.8 ppm
C1-C3 Mercaptans	None	-	10 ppm	.002 ppm
Vinyl Chloride	0-9.6 ppb	-	1 ppm	-
HCl	None	-	5 ppm	-
Benzene	None	-	10 ppm	4.68 ppm
Ethylene	GC/MS Peak	-	-	700 ppm
Trichloroethylene	0-22.2 ppb	-	100 ppm	21.4 ppm
Tetrachloroethylene	0-0.4 ppb	-	100 ppm	-
1-Butene, 2-Butene	GC/MS Peak	-	-	-
Non CH ₄ Hydrocarbons	0-about 100 ppm	3 Hr. .24 ppm	-	N/A

1 National Ambient Air Quality Standards

2 Occupational Safety and Health Administration 8-Hr Standards

ENHANCEMENT OF METHANE GAS PRODUCTION USING AN INDUSTRIAL
WASTE IN ANAEROBIC DIGESTION

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The process of anaerobic digestion was studied as an alternative energy and as a treatment for leather chrome shavings from the tanning industry. The processes used by the tanning industry were designed to prepare the hide in a manner so that all undesirable materials were removed, and so that the proteins were in a reactive state ready to combine with the tannin or chromium used for tanning. The shaving adjusts the thickness of a split tanned hide or skin to generate very small fibrous pieces of tanned hide which contain elevated concentrations of chromium. Within an anaerobic digester, hexavalent chromium is rapidly reduced to the trivalent state. Inhibition is a function of the total concentration of chromium in the sludge regardless of the form in which the chromium was originally discharged. The shavings also contain numerous proteins, fats and nitrogen.

The anaerobic digestability of these shavings was examined using three mesophilic digesters. The capacity of the digesters was twelve liters and these units were based on a thirty-day solids retention time. The shavings, containing four percent chromium, were loaded into two of three digesters, one at a low rate and the other at a high rate.

As more of the shavings were added, the methane gas production increased. Proteins, fats and long chain acids yielded gas compositions higher in methane than carbon dioxide. Most of the metal went to the mixed liquor with less than 1 mg/l being diverted to the supernatant. The presence of a toxic substance and the change of feed did not affect the performance of the digesters. The toxic effect of chrome was mitigated by bacterial uptake and precipitation. In this study, gas production was not affected, regardless of the chromium concentration in the digester, often being higher in the chromium loaded digester than in the control.

BIOCONVERSION OF AN INDUSTRIAL WASTE TO METHANE GAS

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Four unmixed, bench-scale digesters were operated for 89 days on a 15-day solids retention time. The seed and the feed for initial digester stabilization were obtained from a combined domestic and industrial wastewater treatment of the Metropolitan Sewer District in Cincinnati, Ohio.

After stabilization of the units, a wastewater from a drum recycling center was incorporated into the feed of three of the four digesters. The total solids in digesters one, two, and three were increased by 10, 30, and 50 percent, respectively. Digester four, with no industrial loadings, served as the control.

The industrial wastewater was composed of a caustic soda cleaning solution, iron fillings, and industrial detergents from the cleaning of the drums. This wastewater also consisted of residues found in the drums: oils, hydraulic fluids, paints, varnishes, solvents, dyes, coating materials, detergents, waxes, and foodstuffs.

Gas volumes were recorded daily, and routine anaerobic digestion parameters tested were: gas composition, total and volatile solids, pH, alkalinity, chemical oxygen demand, ammonia and organic nitrogen, and the supernatant and mixed liquor content of Cr, Cd, Pb, Cu, Ni and Zn.

Soon after the industrial wastewater was added, the gas volume, being the most sensitive indicator of digestion, dropped off markedly, first in digester three and then in digester two. Coinciding with the faltering gas volume was a dramatic rise in volatile acids and in supernatant metal concentrations. Digester one, though, with the lowest of the industrial loadings, was functioning as well as the control while digesters two and three were undergoing a period of instability.

After two retention times, two and three began to recover; volatile acids decreased, supernatant metals decreased, and the gas volume increased. Recovery occurred first in digester three and second in digester two. The gas volume and the BTU value of the gas in digester three were higher than in digester four, the control.

The quantity and quality of gas produced from digestion were dependent upon the digester feed. Greases and fats, materials with high fuel values in the

feed, increased the gas production and methane content. Another important element in the gas production and quality in this study were the soaps contained in the industrial feed. Soaps, which are comprised of sodium salts and fatty acids, are easily degraded by digestion. Because fatty acids are the precursors of methane formation, a good quality of gas was derived from soaps.

The duration of solids retention and the rates at which the industrial feed were loaded were two important factors in bacterial acclimation. Digester three's performance declined and resumed stability more rapidly than two at the lower industrial loading. Three was at a more appropriate loading to enable the methanogenic bacteria to overcome more readily the metabolic block produced by the industrial waste.

Through the degradation of greases, fats and soaps, longer chain fatty acids are produced, thereby improving gas quantity and quality. The inclusion of this industrial waste in anaerobic digestion shows the potential for a wide variety of industrial byproducts and wastes to be biologically degraded. This study demonstrates the duality of anaerobic digestion: its use as a means of treating industrial wastewater and its viability as an energy source.

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SESSION 3F

ENERGY EDUCATION

THE INTERNATIONAL TRAINING CENTER:
TRAINING IN ALTERNATIVE ENERGY TECHNOLOGY

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EXTENDED ABSTRACT

With the ever increasing energy problems all over the world more and more countries are becoming concerned and worried about how they can improve their energy situation in a World where this commodity is becoming scarcer and scarcer.

Because of the many years in the energy field I have been called upon by many countries to help with their energy problems and even though I've traveled extensively I could not possibly honor all the requests. By the latest count I've had over four dozen requests, many of them coming to me directly, others through the U.S. State Department.

Not able to fulfill most of these requests, I suggested to the State Department that the countries should come to me instead of going to them. By bringing representatives to the Solar Energy and Energy Conversion Laboratory at the University of Florida, many more countries could be helped and really in a better way.

The State Department thought this was a good solution and after the plans for such a program were described we received a 2 million dollar grant for starting such a school which is expected to become a continuous and long range endeavor to benefit a great portion of the world's population.

The training program consists of two 15 week sessions per year with classes of over 40 people per session devoting 8 hours a day to this task. We already have more than three times this number of applicants.

The first class started on 16 April 1980 with over 30 participants from 20 different countries. They were Bangladesh, Belize, Bolivia, Dominican Republic, Ecuador, Egypt, Haiti, India, Indonesia, Jamaica, Jordan, Kenya, Nigeria, Philippines, Portugal, Rwanda, Sudan, Thailand and Tunisia.

The second class started the first week of September with 36 participants from 21 different countries. They are Bangladesh, Barbados, Burma, Costa Rica, Dominican Republic, Ecuador, Egypt, Ghana, Haiti, India, Nepal, Nicaragua, Peru, Philippines, Senegal, Somalia, Sudan, Thailand, Tanzania, Tunisia and Turkey.

The participants learn the theory of utilizing solar energy such as the characteristics of solar energy, the solar properties of materials and then how to put them together to get the desired results such as water heating, space heating, space cooling, refrigeration, cooking, swimming pool heating,

the conversion to mechanical energy, electrical energy, the recycling of liquid waste and fresh water production and the use of solar energy for crop preservation through solar drying and refrigeration. Also covered are the use of solar energy for transportation. In addition such topics as wind, biogas, minihydro, and ocean energy are covered.

The technical aspects, social and economic factors are covered, discussing how things can be done technically and how they fit into their social and economic structure.

Afternoons are spent in actually experimenting and evaluating the solar conversion equipment of the Solar Energy and Energy Conversion Laboratory and in addition the participants design, build and evaluate systems which are particularly applicable to their respective countries and construct these systems out of materials which are readily available to them at home and use methods which apply to their countries. In this manner when they return they can duplicate the systems which they have constructed here and have something ready to be used at home in their countries.

In addition to the above the participants are exposed to guest lecturers from all over the U.S. and the world who are considered top experts in their fields and they take field trips to see some of the larger solar installations in Gainesville which make the media refer to this city as the "solar capital of the world," as well as other parts of the United States.

After the participants return home and set up solar activities and systems in their respective countries we visit them periodically giving advice and help them to make their newly acquired knowledge as useful as possible to their own countries.

In this manner and by this method we can through our efforts help to make the world a better place for future generations to live in.

ENERGY EDUCATION

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ABSTRACT:

This is a two-component sequence taught at Florida A & M University School of Architecture's Introductory Design Sequence.

The intent of these components is to make students aware of passive design principles, and allow them the chance of manipulating form that responds to defined climatic conditions.

The first component focuses on the the analysis of vernacular architecture evolved in diverse climatic and geographic regions. The student chooses two similar climates but different geographic areas, and tries to understand from the comparison what environmental responses are climatically specific, and which responses are culturally specific. The student also explores the cultural patterns and local resources available as programatic determinants. The intent of this first component is to make the student smarter about issues such as ventilation, thermal massing, and heat gain/loss as it pertains to form response. This component is very analytical in nature.

The second component is intended to give the student a chance to use the concepts learned in Phase 1. The student is given a simple set of programatic information and climatic data, which the student has to translate into built form. This translation goes through a series of simulation models, which are modeled on a heliodome and a flow table to test the various solutions' response to sun and wind. The students get feedback on their individual solutions by peer discussions and faculty critiques.

These two components have been successful in that the student is exposed to successful passive solutions and that the student is allowed a chance to visualize through the actual making of form how they might develop climatic specific solutions.

A NEW APPROACH TO ENERGY EDUCATION

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EXTENDED ABSTRACT

Just before Mike McCormack's after dinner speech at the banquet of the 2nd Miami International Conference on Alternative Energy Sources, another direction in communicating energy issues and principles to the public was conceived. For the second such banquet, two conference speakers and members of their family were sharing their table and ideas on how to better accomplish their goals as teachers of energy related subjects. Judy Tavel of Dutchess Community College in Poughkeepsie, New York had the previous day delivered her presentation on "The Role of the Community College in Energy Education" and was relating problem areas to Harold Kurstedt of the Virginia Polytechnic Institute and State University in Blacksburg, Virginia.

The implementation of a preprepared expert-written series of energy related topics in local newspapers had been carried out by Dutchess. Readers could register for college-level course credit and satisfy course requirements by visiting the campus for exams. The logistical difficulties resulting from distance from campus reduced widespread newspaper participation and course credit participation by the public.

Virginia's Land Grant University, Virginia Tech, boasts one of the Nation's outstanding Colleges of Engineering and an Extension Service appreciated and used by the citizens of the state. There are 119 extension unit offices--one in each county and city in the state. There exists then, as an arm of the university, a neighbor and friend near all segments of the state citizenry. The public is familiar with their agents and the procedures necessary to enjoy the services of the Extension Service. The agent has rapport with both the public and the local newspapers. In 1979, there were over 4 million contacts with the populous of Virginia by extension agents through personal contacts, letters, and phone calls.

On campus there are extension specialists with technical expertise in almost any field. It was to the Extension Specialist in Mechanical Engineering, William Mashburn, that Kurstedt took the concept of the combinatorial value of integrated lessons into course packages outlined by university faculty, composed and written by a local newspaper, delivered and implemented through the local extension agents, and carrying

continuing education credit and certification for individuals. The newspaper lessons would be combined with tests and additional information provided locally by the extension agents. Others could read single lessons or courses for self-edification. Assembled lessons could be provided to extension agents for special group study materials, such as 4-H, or handouts as requested. It was through the efforts of Mashburn that the new direction in communicating energy issues and principles to the public was implemented.

During the winter, the objectives, scope, organization, and logistics were established. The extension administration endorsed the concept. It was decided that the busy faculty members should not be encumbered with the burden of carrying out the project details. A newspaper journalist should be hired who would interview the appropriate faculty and research the subjects either as directed by faculty or on their own initiative. This individual, of course, could make or break the entire effort. The university professionals would merely provide facts and review the copy for accuracy. The style would belong to the newperson. The Dean of Engineering agreed to provide support for this person for six months. Extension agents were surveyed for interest and enthusiasm. Overwhelming response and endorsement was received in all but a few cases. The agents had found a new and different outlet for their energies; and local newspapers had found long-term input from a source they had exercised in the past. The courses would be addressed to the average newspaper-reading person who has more than a passing interest in energy. A certain appeal was expected through the satisfaction and reward obtainable by a wide cross section of the public using continuing education certification. The provision of a certificate from a major university provides for the establishment of a degree of credibility among the recipients peers, not possible through just a series of articles. The total course assemblage would provide the entire energy picture.

In early summer the journalist was hired, the series of courses outlined, the initial course outlined, and example lessons written. It was planned that in six months the first course, consisting of ten lessons, would be prepared including quizzes, narrative, and artwork and then submitted as a package to the extension agents along with advertising for submission to the local newspapers.

By the end of six months the course "Energy: An Overview" had been completed as planned. The emphasis of the project had passed to the 119 extension offices throughout the state of Virginia. In addition, four other courses totalling 44 lessons had been drafted and some artwork and other associated effort completed. The four courses included "Nuclear Energy", "Conservation", "Solar Energy" and "Wood Energy". The journalist was retained indefinitely. Information expected by the 3rd Miami International Conference on Alternative Energy Sources, the first anniversary of the concept, includes the number of newspapers running the initial series, the number of people taking the course formally, the

average score on tests, the general reception of the project, and the status of the following courses. The true cost of the project is difficult to ascertain because of free newspaper space, existing extension structure, and participating faculty. However, the newpersons salary, artwork, and printing for five courses and the establishment of the system is estimated to be \$7500.

It is believed that this effort will provide a broader base of energy knowledge for individuals so that they can make decisions and understand long range goals of government and industry. The key to success is the coordination of the capabilities of the newspaper media, the local extension service, and university energy professionals.

ENERGY AND MAN: A UNIVERSITY COURSE FOR NON-ENGINEERS

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EXTENDED ABSTRACT

INTRODUCTION

Since opening in the Fall of 1968 the College of Engineering at the University of Central Florida (formerly Florida Technological University) has offered a series of courses for non-engineers. In the past 12 years, 23,000 students have enrolled in one or more of these courses. One of the major courses in these offerings is EGN 4824, Energy and Man, which has enrolled over 4000 students since it was offered initially in 1973.

COURSE CONTENT

Over a dozen engineering faculty have instructed one or more sections of this course. Accordingly, it has been important to use a text agreeable to all and meaningful to the students. Several texts have been used over the years, and the latest in use is ENERGY AND SOCIETY, by Timothy Healy (Boyd and Fraser, Publishers). Because of the large enrollments, it is difficult to put material on library reserve and it is important that the text be used for a majority of the topics as a source of information. Of course, hand-outs and other class material can be used to supplement text material and to bring data up-to-date. The major course topics, which generally follow the texts that have been used, include: Energy and Power; Definition and Units; Sources and Uses of Energy; Energy Forms and Conversion; Laws of Thermodynamics; Heat Engines; Economics of Energy and Power; Sources of Fuel; Generating Electric Power; Energy and the Home.

ARITHMETIC CONCERNS:

Because the course concerns a topic that is of major interest, many students are anxious to take it. However, because the course is taught by the College of Engineering, most of these students are concerned that the instruction might be too math-oriented for their abilities. For their part, many engineering faculty members are not attracted to the challenge of teaching what they view as numerate materials to a generally non-numerate audience. The text by Healy was carefully chosen because its approach to the subject uses elementary arithmetic, and only to provide comparative values between alternatives. Similarly, many excellent films

have been obtained that provide exposure and insight into subjects and processes that are normally explained in technical, mathematical terms. Encouraged by this approach to communicating important information to a concerned audience, participating faculty members have also prepared carefully contrived examples that expose the students to the thought processes involved in engineering analysis, including how mathematics and the principles of science are used as tools. Course critiques by the students indicate that this approach is generally well received.

STUDENT REACTIONS:

Student reactions range from highly favorable to highly unfavorable. As previously indicated, the majority of students seem to react favorably to the material presented but many dislike use of any arithmetic. The favorable responses from students indicate they consider the course material important, and that it will enable them to use energy wisely and allow them to participate in discussions or debates on energy matters more intelligently. Some have even stated that the material is so important that the course should be required, not just elective. The more typical responses indicate that the students feel they have learned something of value, that they will try to be wise consumers, and that they can now follow discussions on energy policy and energy developments with some discernment. The negative responses usually indicate they were overwhelmed by the arithmetic and they felt the course was too technical for non-engineering majors.

FACULTY REACTIONS:

The general reaction of the faculty members teaching this course is positive, most viewing it as an opportunity to expose an important audience to the technical problems and important energy issues confronting civilization. In spite of course sections containing large enrollments, spirited discussions often begin in class and continue after class in hallways and faculty offices. Such positive exchanges result in much enthusiasm.

CONCLUSIONS:

A course in Energy and Man offered by the College of Engineering at the University of Central Florida has provided a major forum for engineering professors to interact with non-engineering students. Student and faculty reactions indicate that this is an important segment of general education within the university environment, in spite of problems dealing with the technical nature of the course. Many students who would normally not have this opportunity are thus exposed to the broad issues of energy education.

Abstract

ENERGY AUDITING AND CONSERVATION FOR PUBLIC BUILDINGS

By

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The Center for Technology Assessment (CTA) at New Jersey Institute of Technology (NJIT) has been contracted since April, 1979, by the New Jersey Department of Energy (NJDOE) to organize and administer a detailed energy audit program for all public schools, health care facilities, municipal buildings and State colleges. A detailed computerized program and Manual were developed for each type of facility that allowed the local officials or available senior engineering students from NJIT to perform the audits. This program will allow these public facilities to apply for Federal funds for technical assistance leading to a retrofit of their buildings through funded capital outlays. This paper will discuss the audit program and present generalized results and documented energy savings for the numerous buildings that were audited.

In addition, an Operation and Maintenance (O & M) Manual was also created and presented to the people responsible for the public buildings at various training systems throughout the State. The response by the energy managers to this Manual and the overall audit and O & M training program will be discussed.

A PASSIVE SOLAR RESIDENCE FOR A TEMPERATE CLIMATE

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EXTENDED ABSTRACT

INTRODUCTION

The beginning of the project is discussed: the initial inquiry by the owner, the problems of organizing a group to determine possibilities and alternatives, and the arrangements arrived at by written proposal to the owner. The plan of conducting a design competition within the context of an existing undergraduate-graduate seminar as the first phase of the project, and the agreed on process of selection of a winning design are presented. Phase two of the project was to take another semester and would amount to the production of the working drawings, specifications and preliminary costing analysis.

THE ORGANIZATION OF THE SEMINAR

A presentation of the organization of the competition-seminar class is offered and the ensuing discussion follows the several divisions or phases of the seminar. The results of positive and negative occurrences will be presented in the form of comments brought to light using the technique of post-mortem interview. Insights gained as a result of this technique, examination of the course outline (which outline is included as an appendix), and during the jurying of the individual entries are presented.

THE WINNING DESIGN

The architectural design process is discussed as it relates to the winning entry. The results of the application of that design process is displayed and discussed along with exhibits of the drawings and calculations procedures.

THE PRODUCTION OF CONTRACT DOCUMENTS

The working drawings were undertaken in another course titled "The Art and Craft of the House" taught by another Professor. The two Professors co-operated in the process of teaching the student involved about the production of working drawings and specifications.

Another graduate student was recruited to do the cost analysis because of the special skills he had to offer in this endeavor. He had worked as a building contractor for several years before returning to school as a graduate student. Discussion of the costing methods used is advanced with some analysis also offered.

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PROBLEMS ENCOUNTERED IN BIDDING

Some unanticipated problems which occurred during the bidding phase of the project are discussed and insights on these phenomena are presented. Negotiations with building contractors are currently proceeding and hopefully further reporting will include the resolution of difficulties and the actual construction of the project.

THE ROLE OF THE SCIENTIST IN ENERGY EDUCATION

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ABSTRACT

It is generally agreed that energy education is important, but the exact form it should take, and by whom it should be administered are two rather controversial issues. Even more controversial are the energy issues themselves. Social scientists have been forced to take a back seat when they have expressed concern over ethics, values, environmental preservation, supply equity and similar issues. Government, public, and industry have put their faith in technology as a solution to the problem, and, for the most part, energy education has been limited to efforts to get the public to turn their thermostats down in the winter and up in the summer, to caulk their doors and windows, and to drive 55. There has been a general fear of even hinting that the crisis might have a touch of permanence, and that our lifestyles might be affected. Technologists themselves, still priding themselves on reaching the moon, are hard pressed to admit that technology alone may not solve the energy problem.

The principles of exponential growth are too frequently ignored by technical and business people when they argue for increased production of fuels and resources. Failure to recognize that the lifetime of a finite resource is given by $X_L = \frac{1}{n} \ln(nY + 1)$, where n is the annual fractional increase and Y is the expected lifetime at present consumption

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rates, has created a blind optimism that we can expect to continue increasing our rate of consumption.

As responsible scientists, it should be our moral obligation to recognize the inherent catastrophic economic and political ramifications of continued increases in consumption. We should be willing to cooperate with the social scientists in an all-out effort to convince our corporate and political leadership as well as the general public that we are entering a transition from an era of conspicuous consumption to a future that will require careful choices.

COMPUTER-AIDED ENERGY AND
ECONOMIC ANALYSIS FOR BUILDINGS:
STUDENT EXPERIENCE AND AN
ASSESSMENT.

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For the past year, architecture and engineering technology students at Temple University have been using a building energy analysis computer program, a solar heating and cooling evaluation program, and an energy life-cycle cost analysis computer program. A formal research study assessed the value of the general energy analysis program. The solar and life-cycle cost programs were evaluated informally.

The federally sponsored program SOLCOST (1) was installed on Temple's Control Data Corporation CYBER 174 computer in the Fall of 1979. Thus far about 200 student runs have been completed. After 4 weeks of classroom instruction on solar energy applied to heating and cooling of buildings, the students are given 2 hours of instruction on the input procedure and output interpretation for SOLCOST. Most students achieve a successful execution on the second or third try. The response has centered on the value of the economic analysis and its impact on design. Also frequently mentioned is the wide range of system options available on SOLCOST.

The life-cycle cost analysis computer program was developed by the National Bureau of Standards (2) to calculate the savings-to-investment ratio for retrofit projects or the total life-cycle cost for new buildings. The program was oriented toward nonprofit, tax-exempt organizations and is less useful for privately-owned buildings. However, aside from the treatment of taxes, the approach is generally applicable to the private sector. The student response for this program has been an appreciation of the value of life-cycle cost analysis. A recurring comment is "This changed my thoughts completely on building costs."

The author conducted a formal research project on building energy analysis (3). This study determined if computer-aided energy analysis in buildings would enhance a student's comprehension and prediction accuracy of the energy consumption. There are several public and private computer programs available to predict energy consumption in buildings. Most of them are quite involved and include a detailed economic analysis. A search was conducted for a student-oriented program to use in this study, but a suitable one was not found. Therefore, the author developed a program as part of the research.

An interactive program was created and especially designed for use by students. Called Building Energy Analysis Program for Students, BEAPS, it used the Bin Method technique in a block load format. After the

student had become familiar with the input routine, the run time was about ten minutes. Program accuracy has been about ± 15 percent of actual metered data for single zone buildings. This accuracy was also confirmed by another computer program.

The experimental method was a posttest-only control group design. During the Fall of 1979, the author taught Environmental Control Systems in buildings to 35 students. After covering HVAC, energy analysis, and the Bin Method, the class was randomly divided into two groups: Experimental and Control. The Control group took an examination to test their prediction accuracy and comprehension. They were allowed to use only pocket calculators. The Experimental group took the same examination, but they were allowed to use the BEAPS program. Cheating incentive was removed by not making the examination results part of the course grade.

The evaluation instrument consisted of a case study of a building with all calculations presented for a Bin Method analysis. At the end of the study the student was presented with three changes in the original building, and was asked to evaluate the effect of the changes for heating and cooling energy consumption. The answer to each change had to be given in two forms. One was a numerical answer (prediction accuracy) of the new energy demanded by the change. The second answer was a multiple choice (comprehension) of whether the change increased, left unchanged, or decreased the energy demand.

There were 13 students in the Experimental group (computer-aided) and 17 students in the Control group (manual). All statistical analysis were accomplished using the T-TEST Subroutine of the Statistical Package for the Social Sciences, SPSS. A statistical comparison of the grade point averages of the two groups yielded no significant difference. For the variable prediction accuracy, the mean raw score for the Experimental group was 3.08 and for the Control group was 0.59. The difference was significant at the 0.01 level. For the variable comprehension, the mean raw score for the Experimental group was 5.00 and for the Control group was 2.35. The difference was significant at the 0.01 level.

The research study concluded that computer-aided energy analysis improved engineering and architecture students' comprehension and prediction accuracy of energy consumption in buildings. It was also confirmed that an accurate building energy analysis program could be developed for student use.

In conclusion, the experience and the formal assessment indicate that computer-aided energy and economic analysis for buildings allow greater opportunity for integrating and testing of concepts. The fundamentals must still be taught, but for complex problems, the computer program can evaluate design changes in a short time so that optimization is encouraged. It is a fast, powerful learning tool and now suitable for the classroom.

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COMPUTERIZED SEARCHING FOR ALTERNATIVE ENERGY INFORMATION

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Ours is an age of uncertainty. This is especially true of the energy situation and the world's current dependence on fossil fuels to supply most of its energy needs.

Many of the world's nations have recognized the vulnerability caused by their continued dependence on fossil fuels, and have become committed to solving their energy needs through the research and development of alternative energy sources. These research efforts have also brought about a significant increase in the literature covering the various aspects of the alternative energy field.

A researcher is almost totally dependent on his or her ability to acquire and retrieve information, and as the volume of literature continues to grow and become more widely-scattered, the task of acquiring relevant information has become more and more difficult.

Until the early 70's most literature searches were conducted manually, a process that was both time-consuming and limited in potential. Then computer searching revolutionized the entire literature searching process. Libraries, information centers and individuals around the world have been quick to capitalize on its potentials, which include speed (literature searches that once took hours to complete, can now be performed in minutes), and expanded access to information covering all areas of science and technology, and most fields of the social sciences and the humanities.

The process of computer searching is simple to sketch. Seated at a computer terminal, the researcher is in direct contact, via a telecommunication link, with a remotely located information retrieval system. There, machine-readable files called databases are stored. These databases are essentially electronic versions of printed abstracts and indexes such as the Engineering Index and the Energy Index, just two examples of a group of commercially-available databases now totaling over 200. The researcher accesses these databases through a protocol established by the retrieval system and searches by combinations of key words. The primary product of a computer search is a list or bibliography of journal articles, books, conference proceedings, patents and other information sources. The document itself is not retrieved and must be acquired separately. The information retrieved can either be printed out immediately, or printed offline, and sent to the requestor by mail. The use of boolean logic allows the researcher to search an unlimited number of key words simultaneously, and then link or intersect them to delineate the

search topic in a very precise manner.

There are currently three major commercially-available information retrieval systems in the United States: Lockheed Corporation's DIALOG, System Development Corporation's ORBIT, and Bibliographic Retrieval Service's BRS. Certain other systems, such as the U.S. Department of Energy's DOE/RECON system and the National Library of Medicine's MEDLARS, are available to government agencies or contractors only. On the European scene, the European Space Agency's Euronet-DIANE, and the British Library's BLAISE are two of the major systems operating there. Each retrieval system provides its own selection of databases, retrieval protocol and price structure. The cost of a search depends on the type and number of databases searched, and the amount of printed output. A database can be as inexpensive to search as \$25 an hour, or as expensive as \$120 an hour.

ENERGY DATABASES

There are a number of databases available which are devoted to energy information. The largest of these is the DOE Energy Database (EDB), one of twenty databases prepared by the Department of Energy Technical Information Center. EDB is currently available on the DOE/RECON system, but it will soon be made available to the public through commercial information retrieval systems. EDB contains scientific and technical reports of the DOE and its contractors, other U.S. and foreign agencies, universities, research and industrial organizations, in addition to journal articles, books, conferences and patents. All subjects of interest to the DOE are included - conventional and alternative energy sources, their supporting basic and applied sciences, and their engineering, environmental, and socio-economic aspects. The file contains over 560,000 records, and dates back to 1974, with nuclear information dating from 1976.

ENERGYLINE, produced by Environmental Information Center, is available on the Lockheed and SDC systems. It offers broad coverage of the energy field, both conventional and unconventional, indexing literature on the scientific, engineering, political, and socio-economic aspects of energy policy, resources, conversion and consumption. Its coverage dates from 1971, and includes books, government reports and hearings, non-governmental reports, conferences, and articles from over 5000 international journals.

OTHER DATABASES FOR ALTERNATIVE ENERGY INFORMATION

The subject of energy cuts across many disciplines, and can be approached in a variety of ways. Thus, alternative energy information can be found in a great many databases besides those devoted solely to energy. Take engineering, for example. COMPENDEX, the online equivalent of the printed Engineering Index, covers the literature in all areas of the engineering field, including mechanical, electrical, chemical, civil and marine engineering. In this database one can find theoretical and design information on most alternative energy technologies from building

insulation to OTEC, to wind power. ISMEC is another mechanical engineering database which, while less comprehensive than COMPENDEX, contains significant information on thermodynamics, heating and cooling, fuel technology, and mechanical and fluid power transmission.

Chemists and chemical engineers engaged in energy-related activities will find a rich source of assistance in their most familiar database, CA SEARCH (Chemical Abstracts). This immense database, which dates back to 1967, contains millions of references to all types of literature, including patents, and can be searched for any type of energy topic involving chemistry or chemical engineering - coal gasification, for example, or electrochemical cells, or fermentation processes for methane fuel.

Environmental scientists and policy-makers have reason to be concerned about the environmental consequences of new energy technologies. Pollution Abstracts, ENVIROLINE, and Environmental Bibliography, are the three databases that can help here.

Multi-disciplinary databases in the scientific and technical areas can also contain important information. SCISEARCH (Science Citation Index) is good for searching the literature of several subject fields simultaneously, like biology and chemistry for biomass questions, and also allows for citation searching. The NTIS database allows access to governmental agency and contractor reports, and makes DOE reports accessible to those unable to use the DOE/RECON system. SSIE Current Research, the Smithsonian Science Information Exchange, provides a unique index to research in progress.

Businesspeople and social scientists have their own sources of energy information. Predicasts, Inc. produces a number of files, including the E&S Index and PTS PROMT, which abstract information on corporate activities, new products, sales, socio-political developments, and the like from thousands of newspapers, trade and business magazines, and reports. They report regularly on the energy industry. There are also special databases for particular industries - notably P/E News on the petroleum and energy industries and Chemical Industry Notes. For those involved with energy policy, or other social, political, legal or economic aspects of the field, the following files are recommended: PAIS International (Public Affairs Information Service) for current affairs and economics; Social Scisearch (Social Science Citation Index), covering the various social sciences; Legal Resources Index, indexing law journals; and CIS/Index, CRECORD, and FEDREG, which monitor federal government activities.

These and other computer databases can enable the researcher not only to keep up with the expanding world of alternative energy, but to find out more, more quickly, and more easily than ever before. A few sample computer searches illustrate the capabilities of these new services.

A COMPUTER-AIDED-INSTRUCTION PROGRAM FOR TEACHING
PRINCIPLES OF DESIGN AND ENERGY CONSERVATION

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ABSTRACT

This paper describes and illustrates the use of a simulation model as a tool to better understand building design as it relates to energy conservation. The model incorporates an ability to simulate both active and passive solar devices, and is intended to be an aid to students as it helps to improve their ability to make better decisions and gain new insights on energy use and built forms.

Energy exchange in buildings depends on a wide variety of factors such as shape, orientation, and choice of materials; as well as those dynamic externalities which are collectively known as the "climate". A precise description of the interaction between design decisions and external conditions thus calls for considerable familiarity with the mathematics of thermal physics. Calculations are complex and tedious. One cannot expect architecture students to achieve a level of competency in this area while carrying the other requirements of their architectural curriculum. The inability to make quick comparisons between design decisions severely limits understanding and learning, and thus hinders the development and evolution of more effective solutions to the problems of building construction and energy use.

General Principles are best learned and verified through personal discovery. The simulation model presented here is an attempt to provide such conditions within the field of architecture. It is intended to be a teaching tool in that it promotes self-learning and discovery.

The model simulates the thermal environment of buildings, and gives students an ability to manipulate those variables which the builder or architect actually controls during design. A few are :

- Shape or form.
- Materials of construction.
- Orientation of walls.
- Location and number of windows.
- Extent of shading devices.
- Area and efficiency of Solar Collectors.
- Heat storage capacity of Solar Systems.
- Use of Trombe walls.
- Setting and efficiency of HVAC systems.

Output is Diurnal or yearly. Students may choose either tabular or graphic forms of output. Results are generated for the following parameters, to name a few :

- Energy consumption for operation.
- Estimated energy use for construction.
- Estimated energy use for maintenance.
- Life-cycle energy cost.
- Solar heat gain.
- Cost and net contribution of Solar Collectors.
- Diurnal plots of interior and exterior comfort conditions at different times of the year.

This program has proven to be an aid in understanding concepts which were difficult to demonstrate in class or text. A few reasons are :

- It helps to quantitatively evaluate alternative designs.
- Users can quickly manipulate basic forms, orientation to the Sun, and choices of materials.
- Students are presented with the consequences of design decisions in a format which promotes feedback and learning.
- Because the model incorporates the means to simulate both passive and active solar systems, it is a useful way to introduce students to concepts and calculation methods.

A description of the model and the algorithms employed is followed by examples of use. Based on a network of differential equations, the model has been optimized to run efficiently on a small, graphics oriented, microcomputer (6502 CPU w/ 48 K RAM. 280 x 190 pixels). A complete listing , in BASIC, is available free, for those who wish to use it.

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SESSION 4F

CONSERVATION I

THE MANY GLITTERS OF CONSERVATION

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EXTENDED ABSTRACT

Certain mind boggling aspects have crept into the energy problem forefront in the name of conservation. In addition, there are the manifold glitterers of hoopla. On Channel 7, The Good Morning America program of May 6, 1980 exposed us to the latest of electric car drive systems and an airborne bicycle powered by solar photo-voltaic cells. Was this news or hoopla?

A gallon of gasoline costs up to \$1.40 and contains 140,000 BTU. At 14 mpg, an engine drive consumes 10,000 BTU per mile. Otto cycle engine output is 4,000 BTU. Transmission losses reduce energy for overcoming traction and drag to 2,500 BTU. An electric car with 2,500 BTU axle output per mile needs battery output of 3,000 BTU to allow for motor and control losses. Replenishment must be 4,000 BTU to replace battery losses, and through-put at your electric meter will be 5,000 BTU to allow for charger losses. Required input at a fossil fuel utility plant will be 16,700 BTU to account for 30% system efficiency. For a nuclear fission utility plant, required input will be 22,300 BTU to account for lower wet steam turbine efficiency of 60% rather than 80%. The 5,000 BTU per mile is 1.5 KWHR at your meter, and would cost 13.2¢ at a third tier rate of 8.8¢ per KWHR for electric cars. The 10,000 BTU per mile costs 10.0¢ per mile for gasoline fuel. Not taken into account directly are additional electrical power requirements to produce zinc, chlorine and graphite for use in high performance batteries. Ground transportation represents 45% of U.S. energy requirements, and wholesale conversion to battery power would require a tripling of electrical power plants. Electric cars will remain hoopla until most power plants are powered by solar energy, swift water currents and atomic fusion and we can once again afford the price of excess power generation.

A Douglas DC7B can seat up to 95 people, with a gross weight or minimum thrust of 126,000 pounds, which is roughly equivalent to 11,500 HP or 8,000 KW or 30,000,000 BTU/HR at a cruising speed of 360 mph $\frac{1}{17}$. Power required for take-off or maximum speed can be 13,000 HP. The wing area is 1,463 sq. ft., so gross area could be as much as 3,600 sq. ft. If 90% or 3,200 sq. ft. of this area could be lined with photo-voltaic cells, about 130 BTU/HR per sq. ft. could be collected as DC electricity at a conversion efficiency of 43% for a total input of 400,000 BTU/HR, or 117 KW which is 1.3% of the required power. At present costs of \$10,000 per KW, the auxiliary power plant could cost \$1,200,000. This can be seriously considered for powering a man-made satellite out in space, but not down here. Solar-powered aircraft will remain a toy or merely hoopla forever.

Perhaps the media should not be faulted for broadcasting hoopla far and wide. Hoopla is easy to report, fun to report, of immediate interest to viewers with short attention spans which in turn is of primary interest to program sponsors, thus completing the hoopla loop.

In 1978 it was reported that 50% of U.S. housing starts were furnished with electrical heating because "there wouldn't be any more natural gas." This is running in the wrong direction at maximum speed. A modern, gas-fired furnace in a home heating system can extract 3# of 4# of fuel as useful heat, while the remaining 1# is lost up the flue. To do the same job electrically requires the utility system to burn 10# of fuel in a thermal-electric plant or the equivalent of 15# of fuel in a nuclear fission plant which is less efficient. These facts are made painfully clear to utility customers in Northern California where a 3-tier billing system is in use for both electricity and natural gas. Despite the mild climate, space heating makes the third tier at a cost of \$88.19/MW-HR for electricity and \$22.31/MW-HR for natural gas (8.819¢/KW-HR and 66.7¢/Therm) as of August 1980. It is clear from these energy prices that customer conversion of space heating, domestic water heaters and stoves from electrical appliances to gas-fired appliances would have a quick payback. Redi Kilowatt, however, is hardly on the ropes, since lighting, motors and almost all luxury appliances are either electrical or powered by rechargeable batteries, and a total retreat from convenience and progress is not in the offing, or necessary if we turn to alternate energy sources for our electricity.

The advent of many left turns and multiple one-way lanes, separated by curbed planting boxes, has done much to make driving safer on our secondary thoroughfares. The InterState system, at great expense, eliminated crossings and traffic lights, which is fine for drivers passing through. Side effects of the laudable drive for driving safety find our side streets cluttered with stop signs, two-way stop signs and two- and three-way traffic lights. The obvious intent is to put some kind of a traffic control at every intersection of America, and the program is well along. This has had a decidedly adverse effect on gasoline and fuel oil conservation efforts. Internal combustion and gas turbine engines have sharp parabolic efficiency curves. When operated at optimum speed, efficiency is reasonably good but, at very high speeds and very low speeds, efficiency goes to pot. It has been estimated that a car's engine will burn more fuel during a minute of idling than it needs to restart, and in three minutes of idling, it burns as much as it would require to go half a mile [27]. Without sacrificing safety, certain modifications to traffic control notions are necessary in order to eliminate enormous waste. These include:

- (1) Replace one-way stop signs with yield signs. This would encourage rolling stops as opposed to the complete stop. It is far less wasteful of energy to re-accelerate a car which is rolling as opposed to a total breakaway start when this is safe.
- (2) Retain two-way stop signs since the slow-down or stopping of each car is minimal. One-way stop signs can impound a large number of cars at full stop, while a long line of vehicles passes the other way at their leisure. This is wasteful of both patience and fuel.
- (3) Retain two-way traffic lights. Each driver has a 45% chance of hitting it green and, if stopped by red, his wait is short and least wasteful of fuel. Left turn arrows should be reprogrammed to light for a few seconds even if not tripped so that drivers arriving a split second after lights change can proceed to left turn, instead of screeching to a halt and then idling for awhile.
- (4) Eliminate three-way traffic lights by reprogramming to two-way operation. Each driver at these more elaborate intersections has close to

one chance in four of getting through without stopping. This leaves two to three cars at such an intersection stopped and idling while the third or fourth car goes through. This also leaves a majority of cars operating at very low efficiency and it is not uncommon at such traffic-squelching stop lights for cars to have to move up and stop a second time before going through, which is a gross waste of fuel.

Getting back to houses and space heating, there has been tremendous emphasis of adding insulation to existing houses to create R11 and R22 protection. What does this mean? In the past, many wall and roof systems consisted from inside to outside of 1/2" gypsum board, a 3-1/2" gap filled with air or studs as in an exterior wall, a gap of several feet filled with air as in an attic space, 1/2" plywood sheathing, a single ply of tarred felt vapor barrier and a covering of shingles. From a practical point of view, a homeowner can at great expense add 3-1/2" batts between wall studs and 7" batts between ceiling joists. In new construction the cost is less because existing solid surfaces do not have to be removed and replaced, and workmen do not have to poke and pry batts into tight corners at eave lines. Substitute applications which can be blown into interstices have failings, such as flammability, sag when wetted, and poorer insulation ratings. There is an alternate approach. The main protection of even the poorest construction is its air gap. If the number of air gaps is made three or five, the insulation effect would be close to equivalent. If this can be done at low cost, it makes sense. Twin, 3-mil-thick, 2-film sheets of bubbled formation are mass-produced for use as packing material. Such sheets in one or more layers could be used to create the extra air gaps and at very reasonable cost. This merely suggests that there is more than one way to skin a cat and that the use of ultra thick batts may be a case of overkill at first class cost.

In warmer climes, many homesteads are equipped with swimming pools. These normally have to be heated for maximum enjoyment. Formerly this was done using natural gas-fired heaters, and the norm was equal utility bills each month of a year. In the wintertime, the house was heated and the pool was not. In the summertime, the pool was heated and the house was not. Gas bills could be highest in Spring and Fall when both were heated at times. The old way is impractical in light of present gas billing. Today, pools are heated by solar heat augmented in various ways more often than not. One extreme is a total flat plate collection system which can add 6°F by day and drop 2°F by night, costing thousands of dollars. The other is a flotation cover of 2-film bubbly plastic, often blue in color, which adds 3°F by day and loses 1°F by night, costs hundreds of dollars but does not require pumping power. The less expensive approach all too easily can hold swimming pool water between 88°F and 93°F. To prevent algae overruns requires constant chlorination and occasional removal of some or all of the solar heat collecting cover.

The installation of certain solar collection devices as per the current federal and state tax collection agencies results in rebates ranging from 15% of cost for federal income tax returns to 55% for California income tax returns. Many states have similar provisions. Such tax write-offs benefit well-to-do people. In California the Public Utility Commission (CPUC) has introduced

a three-tiered system of billing for electricity and natural gas supplied to residential units. This system benefits institutions, businesses and tenants in small apartments who pay at the first tier level [3]. People living in nested condominiums are paying for half of their energy use at the second tier prices. People living in separate houses or large condominiums are paying for a third at second tier prices and a third at the third tier prices. America does not have a comprehensive energy policy. Such a policy has been suggested at every level of government [4]. In the absence of a comprehensive energy policy, it is urged that there be no more cheap shots taken by activist political agencies. The initiation of a comprehensive energy policy requires a national consensus as to what to do. Once we have decided what we will do is a good point of departure for the formulation of taxation with representation.

Conservation has many glitters. Some are good, but many are bad. We were not going to leave 20 billion barrels of oil underneath the tundra for carabou convenience while buying oil at OPEC prices, yet groups slowed this source of energy for three years. We are not going to leave California offshore oil untapped for seagull convenience as long as an energy crunch exists. Conservation has much merit, but should not be pushed to block progress anywhere, every time. America needs selectively intelligent conservationists, but we must not let erroneous mythologies blunt our communal efforts.

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CONSERVATION — AN ABUNDANT, ATTRACTIVE AND ECONOMICAL ENERGY RESOURCE

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ABSTRACT

Energy consumption in the United States, in equivalent barrels of oil, is currently approximately 37 million barrels per day. Half of this consumption is petroleum, with the remainder mostly in natural gas, coal, nuclear and hydroelectric. Depending upon the assumptions made, it is a straightforward exercise to show that by the use of existing technology, consumption can be reduced up to 24 million barrel equivalents per day without eliminating either air conditioning or the personal automobile. Furthermore, the economics of such a program are more attractive than the economics of alternative energy production schemes. It is proposed that a program be initiated to reduce energy consumption an average of 2.2 per cent annually for the next 50 years in order to achieve the 24 million barrels per day savings.

The program involves replacing existing machinery, processes and buildings as they wear out with more efficient substitutes. An attempt is made to estimate the "true cost" of fuels such as coal, oil and nuclear in order that a comparison can be made with the cost of the proposed "con fuels".

TRENDS IN THE CONSERVATION OF ENERGY
IN THE UNITED STATES
1965-1980

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EXTENDED ABSTRACT

INTRODUCTION

This paper focuses on empirical evidence of conservation actions (motivated by price, costs, regulations, or for any reason) in the United States, with special emphasis on the post 1973-1974 period. An overview of total energy use by economic sector - residential, commercial, industrial, and transportation - is presented. Gross indicators of energy intensity are tracked over the time period 1965-1978. Purchases of conservation and more fuel efficient equipment are described. Finally, increased uses of renewable resources are documented.

Sources of information include newly developed (or modified) data collection systems initiated by the Department of Energy (or by the Bureau of Census at DOE's request), the Department of Transportation, the Internal Revenue Service, and the Environmental Protection Agency.

TRENDS IN U.S. ENERGY CONSUMPTION

Since the Arab Oil Embargo of 1973-1974, the energy consumption to gross national product ratio for the United States has been in a steady decline. This means that the U.S. is becoming more fuel efficient in its production of total goods and services. The Energy Information Administration estimates that the decreasing trend in the energy to GNP ratio will continue at least through 1981.^{1/}

^{1/}p.44, Annual Report to Congress, Volume 3, Energy Information Administration, DOE/EIA - 0713 (79)/3.

Total energy consumption declined for two years subsequent to the embargo, but began to increase again beginning with 1976. In 1979, however, the same amount of energy was consumed as in 1978. This was true even though the GNP increased by 2.2 percent.

Consumption patterns by end use sector have been varied over the 1973-1979 period. Of particular interest is the continual growth in energy losses at electric power plants, from 19 to 22 percent over the 7 year period. Also of interest is the growing use of petroleum in the industrial sector. The paper describes these sectoral trends and others in more detail.

GROSS INDICATORS OF ENERGY USE INTENSITY

Gross indicators of energy use intensity are tracked over the 1965-1970 time period. These indicators include: energy consumption per dollar of gross national product, per-capita residential energy consumption, energy consumption per licensed driver, energy consumption per commercial building square foot of floor space, automobile fuel economies (new cars and the fleet), and energy consumption per dollar of gross product originating in the industrial sector. Most of these indicators have shown patterns similar to overall energy consumption. That is, positive movement in the two years subsequent to the Arab Oil Embargo, general degradation for the next three years and then improvement in 1979.

PURCHASES OF ENERGY CONSERVATION EQUIPMENT

Information on the purchase of energy conservation, and improved fuel efficient equipment is provided. These include: insulation, storm windows and doors, caulking, heat pumps, and higher efficiency vehicles, including diesel automobiles. As an example, the fuel efficiency of new cars declined throughout the

1970 to 1974 period, going from 15.2 to 14.4 miles per gallon. Starting in 1975 new car fuel efficiencies began to increase, and the trend has continued throughout the first few months of 1980. Domestic new car efficiencies have increased from 14.4 mpg in 1974 to 21.6 mpg in 1980.

USE OF RENEWABLE RESOURCES

Information on the purchase and use of renewable resources include solar collector heating systems, wind energy conversion systems, geothermal power systems, alcohol fuels, wood as a fuel, and municipal and agricultural wastes as fuels. As an example, the table below provides estimates developed by the Bureau of the Census on the number of solar heating systems installed in new homes during 1978 and 1979.

SOLAR SYSTEMS INSTALLED IN NEW SINGLE - FAMILY HOMES AS A PRIMARY HEATING SOURCE

(90 percent confidence interval, in thousands)

	<u>1978</u>		<u>1979</u>	
o Solar Systems Installed	8.1	- 12.5	5.8	- 9.6
for space heating	1.1	- 3.7	1.0	- 3.2
for water heating	3.5	- 6.5	2.5	- 5.7
for space and water heating	1.5	- 4.3	0.6	- 2.4
o Total Single Family Homes	1,324.2	- 1,414.2	1,257.6	- 1,343.2
o Percent of New Homes having Solar Systems	0.519	- 0.92	0.44	- 0.74

CONCLUDING REMARKS

Information provided in this paper indicates that individuals and businesses are reducing their waste of energy by such actions as turning down thermostats and eliminating unnecessary travel. Additionally, they are investing substantial amounts of money in higher energy efficient equipment or equipment which converts renewable resources to energy. Fossil fuel price escalation, changes in federal and state tax laws, and a growing "conservation ethic" are all contributing factors to decreasing energy consumption.

ESTIMATING THERMAL PERFORMANCE OF BUILDINGS
AND ENERGY CONSERVATION IN HOT-ARID CLIMATES

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EXTENDED ABSTRACT

The current need for energy conservation has led to re-evaluate the factors that affect the internal thermal comfort conditions of buildings. Modern building design and the use of new building materials consume over 30% of the total energy resources for winter heating and summer cooling. Significant energy savings can be achieved by judiciously selecting materials with appropriate design technique.

This paper discusses how indoor environmental temperature could be improved passively for an office building in climate and location like that of Cairo, Egypt. It is assumed that the room in a multistorey office building and surrounded by rooms undergoing the same thermal history as the one considered. The room is occupied and has one facade and five internal massive walls. It is assumed cube of 3m side with a shaded and unshaded facade of variable glazing areas.

Two building materials have been chosen; solid clay brick plastered both sides for office I and solid concrete prefabricated units plastered both sides for office II with 1, 3 and 10 ACH ventilation rates. The influence of N.West/East/South orientations on the mean and peak indoor environmental temperature during summer and winter are studied.

The temperature response to various forms of heat inputs has been determined according to the admittance procedure [1,2]. A computer programme is developed to take into account the effect of the various conditions.

The results showed that all mean environmental temperatures of all cases decrease with the increase of ventilation rate, since ventilation is the main mechanism of abstracting heat from the room. The peak to mean internal environmental temperature is decreased with the increase of ventilation rates for unshaded facade while increased slightly for shaded facade.

Figure 1 shows the effect of increasing the ventilation rate from 1 ACH to 10 ACH on the calculated peak indoor environmental temperature for office I with shaded and unshaded south facing of 25% and 50% glazing area. It is clear that $t_{ei,p}$ are much decreased by increasing the ventilation rate.

Figure 2 shows the effect of increasing the proportion of glazing area of the facade from 0% to 100% on $t_{ei,p}$ at different values of ventilation rates. It is seen that $t_{ei,p}$ are much increased by increasing the glazing area.

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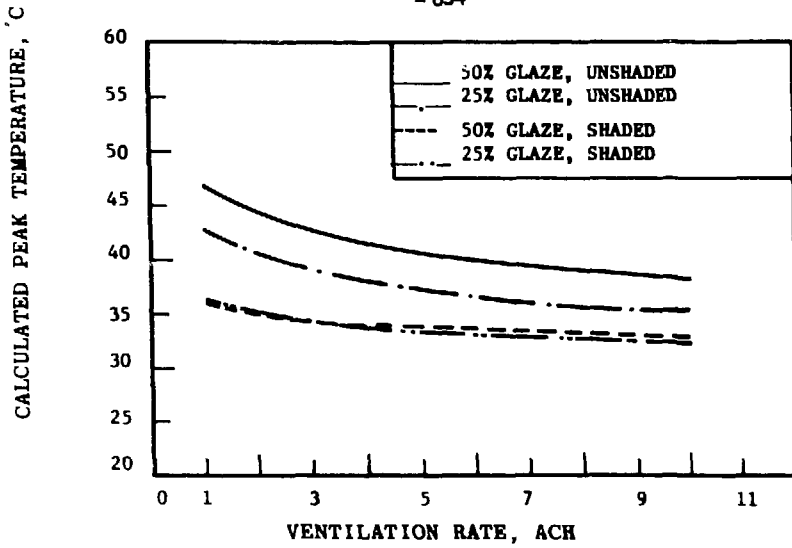


FIG. 1 EFFECT OF VENTILATION RATE ON THE PEAK TEMPERATURE FOR UNSHADED AND SHADED SOUTH FACING WITH DIFFERENT GLAZING AREAS-SUMMER CONDITIONS.

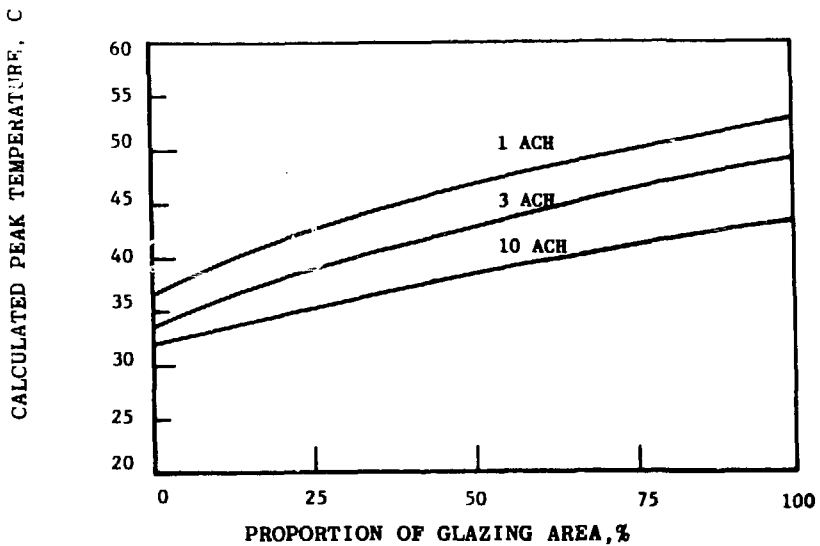


FIG. 2 EFFECT OF GLAZING AREA ON THE PEAK TEMPERATURE OF UNSHADED SOUTH FACING AND VARYING VENTILATION RATE-SUMMER CONDITIONS.

THE REDUCTION OF HEAT FLUX BY USING REFLECTING SHEETS

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ABSTRACT

In this paper, the effect of placement of reflecting sheet in air-gaps on thermal performance of the system and optimum number of air-spaces with and without reflecting sheets is discussed. One face of the roof is exposed to solar radiation and ambient air and other one is in contact with room air at constant temperature.

It is inferred that dividing an air-gap into many reduces the heat flux coming inside the room and seen that at the most one may use effectively only four air-gaps. However, the introduction of reflecting sheets allows only two air-gaps. It is seen that the use of reflecting sheet is more economical and gives a better performance than the water film system.

MULTI-PLATE GLASS SYSTEMS THERMAL ANALYSIS FOR
BUILDING ENVELOPE ENERGY TRANSFER

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Abstract

Energy demand attributable to heating and cooling of buildings can be lessened strictly correlating architectural windows heat gain to seasonal heating and cooling requirements. The development of design tools adequate to climatic long-term data availability may be of great benefit in reducing energy consumption.

The solar transmission and heat transfer problem related to multiplate window systems requires computations of driving functions, as insolation, and static system parameters, as glass bulk transmittance. Since some of the latter are strongly directional functions, an hourly driving function model seems well suited for an accurate system simulation. Such long-term heat gain estimations seem to have not been widely analyzed.

In this paper an analysis is presented to predict, on the basis of monthly means of hourly irradiation estimate, multiplate architectural window systems heat gain. The mathematical model is extensively expounded; main assumption are: quasi-steady state system response, indoor air temperature constant, insolation and air temperature driving functions varying hourly in the diurnal cycle and monthly in the yearly cycle. Insolation estimation is based on the monthly means of daily values of global radiation received on a horizontal surface.

Main objectives of this work are to clearly state the mathematical model, to present and discuss first results and to develop a simulation tool which should lead to gain an understanding of the problem such to obtain next a general engineering design procedure.

Numerical computations for Naples (Italy, 40.85 deg. N of latitude) and for single and double pane windows of clear float glass are presented, for principal orientations, both for the diurnal and the yearly cycles. The double pane window shows its better behaviour compared to the single pane for both winter and summer conditions. Referring to a typical apartment (a plant of 100 m², windows areas 10 m² -south-, 2 m² -north-, 2 m² -east/west-) the seasonal heat gains are -258 kWh and 590 kWh, for the single and double pane windows respectively. This implies a reduction of 38% of the heating energy demand when a UA of 64 W/K is assumed for the opaque walls and 1300 Kd are chosen for the winter season. Payback time analysis shows that the first cost differential between single and double glazings, related to the selected typical apartment, can be paid back in less than ten years.

THE QUICK IDENTIFICATION OF SCHOOL BUILDINGS
WHICH HAVE A HIGH ENERGY CONSERVATION POTENTIAL

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The State of West Virginia has approximately 1300 public schools. Limited monetary and personnel resources make it impossible to have an energy engineer visit each school and evaluate its energy efficiency. Because of this, in 1978, the West Virginia Department of Education and the West Virginia University College of Engineering developed a computer program to analyze each school's energy consumption. The intent was to identify quickly those schools which had the greatest potential for energy conservation and to have the available energy engineers concentrate their efforts upon the schools identified. The computer program was based upon information concerning the school provided by response to a questionnaire sent to the school principal.

Because of the limited resources available, it was of utmost importance that the computer program identify the correct schools.

The computer program had two key aspects:

1. Develop a questionnaire to which a person, who does not have a technical background, can respond, yet have the answers provide direct information for a technical analysis.
2. Use correlations developed nationally to obtain additional information in an indirect manner (for example: building construction date foretells the amount of insulation in the walls).

The state of West Virginia has used the program for two years and has conducted sufficient site visits to determine the accuracy and success of the program. This paper discusses three aspects related to the accuracy of the computer program.

1. The accuracy of the data received. Comparing data provided by the schools with data obtained by a visiting engineer indicated that incorrect answers contributed 48% to the estimated error in the computer analysis. This error was attributed to misinterpreting a question or carelessness on the part of a respondent.

2. The accuracy of correlations used in the computer program. The program used correlations based upon historical building construction techniques across the United States. It was learned

that deviations between common building practices in West Virginia and the United States could account for 52% of the remaining error in the analysis.

3. The validity of the computer model used. The computer model used was based upon a "degree-day" analysis. Comparing the results using this model with results using a "modified degree-day" analysis yielded results differing on the average by less than 10%.

On the average, the original computer analysis was quite accurate. The average error was only 4%. However, the error in a particular analysis could be quite large with only 12% of the analyses being accurate to within 10%. Using the new correlations determine through this investigation, and also assuming that accurate data can be obtained in the future, the new computer program would yield 48% of the analyses accurate to within 10%.

WASTE NOT - WANT NOT

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ABSTRACT

The variety and extent of usage of used automotive parts is relatively unknown in North America. Yet there is an extensive industry in the U.S. and Canada that recycles used parts from: Autos, Trucks, Busses, Motorcycles, Farm Equipment and Construction Equipment, at the rate of seven to eight million vehicles a year. In so doing, the industry saves the U.S. alone the equivalent of some 80,000,000 barrels of oil a year.

Parts from wrecked, damaged, and abandoned vehicles are used in the repair of other vehicles by: new car dealers, used car dealers, body shops, vehicle fleet owners, services stations, and retail customers. Automotive parts that are slightly damaged or worn are also sold as "Cores" to the automotive parts rebuilding industry, for repair and resale to consumers as rebuilt: engines, transmissions, alternators, generators, starter motors, etc. The automotive dismantling and recycling industry is the principle supplier of "Cores" to automotive rebuilders, and thus contributes significant additional energy savings through recycling rebuildable parts. The rebuilding of automotive parts saves 95% of the energy that went into the original manufacturing of those parts.

A tertiary product produced by the automotive recycling industry is scrap metal from motor vehicles. This includes: iron, steel, aluminum, lead, copper, zinc, as well as other materials. The industry is the major supplier of ferrous metals to the scrap processing industry, supplying some 37% of all ferrous metal recycled, or about 17 million tons annually. In the future, as the amount of aluminum in automobiles rises to 200 pounds per car on the average, the automotive dismantling and recycling industry will have a significant impact on the recycling of aluminum. Likewise, as more and more vehicles with Catalytic Converters become available to these Recyclers, the more this industry will affect the price and recyclability of Platinum Group Metals.

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This paper will examine the process of recycling used automotive parts, "Core" parts, and scrap metal. The implications of this recycling process will be discussed in light of: insurance rates, repair of vehicles, abandoned vehicles, future equipment requirements, energy savings, legislation, regulation, and recycling in general.

This paper reveals the private sector's views on recycling in terms of practical, on-going, efforts to recover the maximum amount of energy from wrecked and derelict motor vehicles.

AN ANALYSIS OF THE FACTORS INFLUENCING
INDUSTRIAL ENERGY CONSERVATION

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INTRODUCTION

Recent years have seen a marked improvement in industrial energy efficiency. The amount of energy needed to produce a unit of output (measured in nominal terms) has fallen precipitously in almost all industries. The origin of this improvement is not as transparent as its existence. To be sure, a portion of the achieved reduction in energy intensity can be attributed to housekeeping measures. This, however, is not the sole explanation for the observed amelioration. The distinct possibility exists that some of this efficiency improvement is illusory. That is, the product mix from industries within various two-digit SIC categories is changing so that the output of the less energy-intensive industries is growing relative to the output of the more energy-intensive and, consequently, although it is true that efficiency is increasing, this component of the increase is not attributable to conservation efforts. Additionally, the dramatic escalation in the price of energy has provided a considerable incentive to conserve. These effects must be discounted before making any inference about the possibility that non-price induced conservation is responsible for some of the observed improvement in industrial energy efficiency. Finally, the level of economic activity has fluctuated over the period for which the energy efficiencies are computed. To the extent that differential impacts on industries within the two-digit SIC categorization exist, then the reported efficiency improvement will be misleading.

DEMAND FOR ENERGY

It is useful to understand the nature of the demand for energy in the industrial sector. The demand for energy in the industrial sector is a derived demand. That is, it comes from the demand for the product for which energy is used to produce. To the extent that production technologies remain unchanged over time, industrial energy demand derives from the complex workings of domestic and international economic growth and contraction in addition to changing consumer preferences.

In the context of this nature of the demand for energy in the industrial sector, the elements affecting the demand can be characterized as follows: factors which determine the demand for products and consequently the level and composition of output; process factors which determine the energy-efficiency for a given level of production; the time element which affects the rate of technological innovation and adoption; and financial factors including access to capital markets. The impact of each of these elements in the ten most energy intensive two-digit SIC industries is the object of interest.

RESULTS

It is extremely difficult to make a precise, quantitative assessment of the impact of the myriad of factors affecting the improvement in industrial energy efficiency. It is certainly not correct to conclude that housekeeping measures alone have led to the observed improvement. Changing product mix among four-digit SIC industries within the same two-digit classification, variations in capacity utilization, and energy price increases as well as technological innovations have all contributed to part of the realized reduction in energy use per dollar value-added. Unfortunately, data limitations as well as modeling weaknesses prohibit an exact delineation of the impact of each of the factors on the increase in energy efficiency. The best that can be done - and quite convincingly so - is to qualitatively show that, unequivocally, these factors had an impact on the efficiency with which energy was used in the manufacturing process for the ten most energy-intensive industries for the period 1971 to 1976.

GEORGIA'S STATE INDUSTRIAL ENERGY CONSERVATION PLAN

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The Industrial Energy Extension Service is a voluntary program aimed towards facilitating energy conservation efforts in Georgia industries. Its ultimate goal is a 10 to 20 percent reduction in the projected 1980 energy needs of Georgia's industries. The savings to the state's industrial community from this program could reach a quarter of a billion dollars.

The Georgia Office of Energy Resources (OER) is sponsoring the program, under a grant from the Department of Energy, as a major part of an overall State Energy Conservation Plan. The Industrial Energy Extension Service (IEES) is operated through the Georgia Institute of Technology. Staff is drawn from the engineering college and the Engineering Experiment Station.

The program is structured to focus on Georgia's major industrial energy users. It gives specific attention to the Food, Textile, Chemical, Stone, Clay and Glass, and General Industry Groups. Together, these groups use over 79 percent of the total energy consumed in Georgia's industrial sector. The IEES is aimed at accelerated energy conservation in these industries through options which minimize capital investments. Major elements of the service include:

- Development of data on energy usage patterns in industrial plants.
- Industrial plant energy surveys.
- Technical assistance on plant installations and retrofits.
- Development and dissemination of case studies.

- Formulation of educational materials for employees.
- Initiation of in-plant energy organization.
- Development of management procedures for tracking and reporting energy usage.
- Continuing education activities.
- Development of workshops and texts.

Energy surveys are conducted by teams of trained, experienced Georgia Tech engineers. The teams typically make a series of visits to each plant being surveyed. Data is collected on current energy use patterns, and each significant energy user's operating efficiency is analyzed. Modifications to both operational practices and the equipment of processes themselves are then considered, including the comparative economics of implementation.

Formal reports are prepared with specific energy conservation recommendations and supporting rationale. Potential savings are quantified for each recommendation, in terms of both energy and cost. Examples of basic concepts addressed in the surveys are:

- Energy management program.
- Heat recovery.
- Alternate fuels.
- Combustion efficiency.
- Process modification.
- Electrical demand control.

A series of computer programs has been developed to facilitate analysis of frequently encountered potential energy conservation situations. These include programs on boiler tune-up, installation of an economizer on combustion units, relocation of air compressor intakes, heat recovery from

dryer exhausts, and electrical demand control.

In conjunction with its technology transfer efforts, the IEES has prepared several technology and industry specific workshops in areas such as boiler efficiency, textile batch processes, solid fuels combustion, and heat recovery. Detailed handbooks have been written by staff engineers for use in these workshops, and the seminars have proven quite popular with industrial representatives.

The project has just been renewed for its third consecutive year of funding and the results have been quite encouraging (see Table 1). However, many barriers to realizing full conservation potential still remain. It is our hope that continued efforts along the lines of the IEES will help to lower these barriers and enhance the future energy outlook of Georgia and the U.S.

TABLE 1

Program Highlights 8/1/77 - 3/31/80

- Plant Visits: 465
- Total Plant Contacts: 739
- Audits Completed: 187
- Workshops Conducted: 43
- Mailing List: Approximately 6,000 Business and Industry Representatives
- Actual Energy Savings by Georgia Industry During Program Existence: 41.1 trillion BTU's
- Actual Energy Cost Savings by Georgia Industry During Program Existence: 109.6 million dollars

ABSTRACT

PRACTICAL CONSIDERATIONS IN THE FIRING
OF INDUSTRIAL WASTES

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Rapidly increasing prices and possible shortages of fuel have caused an economic crisis in our country that has influenced all areas of our society. In particular, our energy intensive industries are now in a very difficult situation because price increases and the possibility of fuel curtailment pose a serious threat to their economic viability.

In industries where waste material might be used as a fuel there is the possibility that dependence of fossil fuels might be reduced. The use of waste material as a fuel could have a significant impact on the energy consumption of industry groups where large amounts of it are being generated. In some cases, an added benefit would be the elimination of a waste disposal problem along with associated cost.

Although the firing of waste materials could alleviate fuel and waste disposal problems, it could also create other problems. For example, the use of solid fuels would generate storage and handling problems not encountered with conventional fuels. Also, problems related to operation, maintenance, and pollution control may be encountered. Information that would be helpful in resolving some of these problems can be obtained, but only from widely scattered sources.

This paper will accumulate information related to solids handling, storage, combustion efficiency, maintenance, and environmental problems in facilities fired with industrial wastes. Practical examples of the types of systems that could be converted to fire industrial wastes will be given along with an example of a cost effective conversion.

Finally, an example will be given which will illustrate how improving the combustion efficiency of a facility fired on industrial waste can reduce operating cost or increase production. An improvement of this type could result in a reduction in the use of fossil fuel for a facility partially fired with waste materials or might allow expansion of a production facility whose thermal energy is being supplied entirely with waste material.

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SESSION 5F

ENVIRONMENT AND HEALTH

AIR POLLUTION: ITS EFFECT ON THE DESIGN AND PERFORMANCE
OF SOLAR ENERGY SYSTEMS

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EXTENDED ABSTRACT

The design and performance of solar energy systems for many potential industrial heating processes will be critically affected by local insolation conditions. The effects of air pollution are considered and reviewed. A study of insolation data for Alhambra, California (9 km south of Pasadena) shows that during a recent second stage photochemical smog alert (>0.35 ppm ozone), direct beam insolation at solar noon was reduced by up to 40%, and the total global by 15%, from control clean air values. This was attributable primarily to air pollution. Effects due to advected smog have been detected 200 km away in the Mojave Desert. This effect is illustrated in Figure 1.

The study also analyzed the sensitivity of solar power plant performance (both photovoltaic array and parabolic solar thermal dish systems) and cost of energy to possible reductions of insolation due to the presence of air pollution. Using computer simulation programs developed at JPL for performance and economic modeling of solar thermal and photovoltaic power systems, fixed percentage reduction of the insolation inputs (Phoenix, Typical Meteorological Year data) were run as case studies.

The simulated effects of these insolation reductions on plant output and the unit cost of energy are examined.

The frequency with which smog occurs in the Los Angeles Basin indicates that even on annual basis the reduction of insolation due to smog is significant. Already there is evidence that some forms of plant life are seriously damaged by photochemical smog. One study has put the cost of yield reductions in cotton crops in California's San Joaquin Valley in 1975 at \$30-40 million. Solar "biomass" schemes may, or may not, be similarly affected but the implications could be serious for California's solar-based electricity program which is developing rapidly, partly in response to growing social and environmental concerns about nuclear and coal-fired power stations.

A concentrating industrial process heat system has been installed in Pasadena. The use of low cost photovoltaic panels on relatively high-density solar housing is also conceivable without infringing on the sun rights of surrounding structures. When framed in the context of this potential market for solar applications in and around the Los Angeles Basin, the annual loss of even a few percent of sunlight would be a severe penalty, and the occurrence of intermittent smog episodes could result in major disruptions in the energy supply system. To varying degrees, this conclusion is relevant for many urban areas and industrialized areas as, for example, Sydney, Australia.

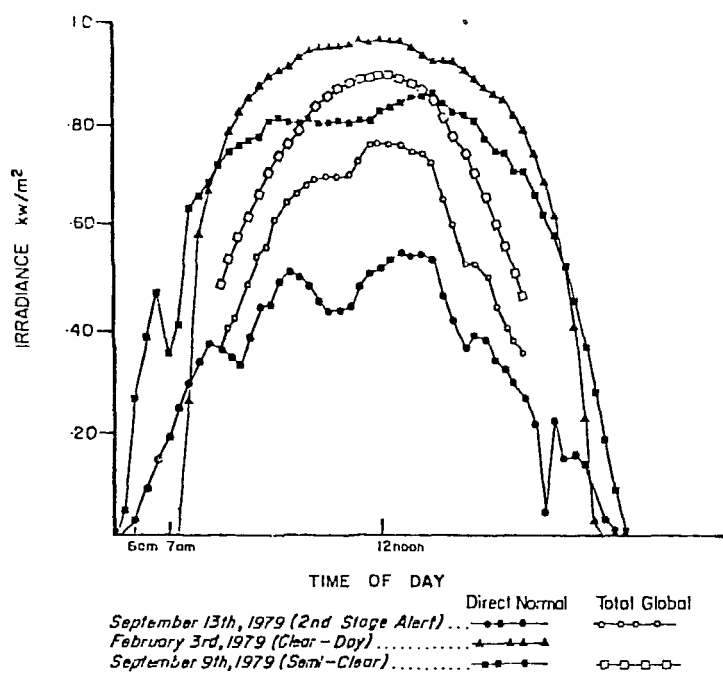


Fig. 1. Insolation Profiles for Alhambra Ca 1979.

THE CONTRIBUTION OF WOOD COMBUSTION TO
NATIONAL POLLUTANT EMISSIONS

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EXTENDED ABSTRACT

As proponents of the concept of renewable energy resources, we have been looking critically at the role of wood as an energy resource. The effect of increased wood combustion on air quality, and the possible health effects which could result, are a major concern.

Three phenomena have occurred in the last ten years which cause concern over the contribution of wood combustion to air pollution. First is the development of the airtight woodstove, which has changed the nature and quantity of emissions from each cord of wood burned for residential heating. An airtight stove is loosely defined as one which restricts the inlet air to produce efficiencies on the order of 40-60%. Second, due to the increasing costs of convenient fuels such as oil and gas, there has been a phenomenal increase in the amount of wood burned for residential heat needs. According to a Booz, Allen, and Hamilton report to the Department of Energy (1), annual woodstove sales rose from 0.16 to 1.2 million units during the years 1972-1978, and will remain in excess of one million units for the next five years. Accurate figures for residential wood consumption are not available, but current usage is probably in excess of four million homes at four cords per year. Third is the phenomena of renewed interest in wood as an industrial fuel, as exemplified by Dow Corning's construction of a wood fired cogeneration system which will provide steam for heat needs and 22MW of electrical output.

These three phenomena cause concern over air pollutant emissions and the possible consequences of unregulated fuelwood harvest (e.g., erosion and deforestation). Data on emissions from airtight stoves have recently become available, while emission data from industrial wood-burning boilers has been available for years. DeAngelis, et al. (2) performed the most complete characterization of woodstove emissions to date, but their data were taken for airtight stoves operating under very high-fire operating conditions. The burning rates in their study resulted in heat release rates of 63-150kW. Taking into account the measured stove efficiencies, these burning rates corresponded to a net heating rate of 23-56kW to the dwelling. Much operation of woodstoves occurs under "damped down" conditions, and available data (3) indicate that total particulate and condensable organic emissions (TPCO) are worse in this mode.

Thus, the data of reference two probably represent a "lower limit" for TPCO emissions for the two types of stoves tested. Emissions from stoves under different operating conditions are currently under detailed study (4).

A rough comparison of the air pollution cost of different fuels used for heat generation can be made by comparing the emissions of the fuels on a micrograms of pollutant per Joule of heat release ($\mu\text{g}/\text{J}$) basis. This basis allows rapid comparison of fuels with vastly different heating values or moisture contents, and is really a pollutant cost to energy benefit ratio. This technique can only be used if the heat-producing devices (e.g., woodstove, distillate oil boiler, gas furnace) have approximately the same efficiencies, as is true in this case.

It is clear that wood, as currently burned in residential woodstoves, contributes substantially to the total national emission of carbon monoxide; and wood's share of respirable particulate is also potentially overwhelming on a localized basis (5). There is obviously going to be a great deal of resistance to the idea that governmental regulation of woodburning is necessary. However, currently available data indicate that the situation may be serious.

What then are the regulatory options? For many years, the British have required solid fuel heaters to be low smoke emitters, but the British had the "killer smogs" of the 1950's to help impress people with the seriousness of the problem. If the government was to decide that new stoves in the United States had to meet emissions standards, there would be three major problems in addition to citizen backlash. First, millions of "dirty" stoves are already in use. Second, it is not clear that the technology exists to produce a clean-burning, efficient stove at a price which is reasonable compared to current stove prices (ca. \$150-800). Third, regulation requires the identification of users either through the users acquisition of the appliance or the fuel, both of which can be bypassed by homemade stoves and home-gathered fuel wood. Solutions to this problem require public monitoring and reporting of violators. Although R. C. Hill has developed a woodburning central heat system (6) which appears to have a relatively clean exhaust, the unit operates only under high-fire conditions (necessitating an energy storage system in addition to the burner) and costs on the order of \$2000. Thus, it is in no sense a cost-effective replacement for currently sold radiant heaters.

The solution we espouse is development of a device which could be sold as a retrofit for existing stoves. A catalytic convertor is a candidate for this task, and holds forth the promise of simultaneously reducing air pollutants, increasing stove efficiency, and reducing chimney fires and the need for chimney maintenance. One stove manufacturer (Franklin Cast Products, Warwick, RI) has recently begun marketing a stove with a monolithic, noble-metal catalyst in the stove; and it is claimed that the convertor does eliminate virtually all chimney deposits. This is an

indication that the catalyst is oxidizing the particulate and condensable organics emissions, but no hard data are yet available to substantiate this. A retrofit version of this idea presents challenging engineering problems--the device must not plug up and allow poisonous gases into the dwelling, and if induced draft is required, the device must not fail in the event of a power failure.

In summary, wood has the potential to provide a minor but significant portion of our energy needs. The air pollution cost of currently practiced residential wood combustion is intolerably high. Regulation of solid-fuel combustion emissions from residential heaters will probably be necessary to protect public health. A vigorous research program, geared toward development of clean-burning stoves and a retrofit device to clean up stoves already in use, is necessary to allow wood to be utilized to the fullest extent as an energy resource.

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ASSESSMENT OF THE ENVIRONMENTAL IMPACT
OF POWER PLANT FLY ASH

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Most coal fired utility and industrial boilers burn pulverized coal and generate large amounts of fly ash. The fly ash consists of finely divided particles of inorganic oxides that are either entrained in the flue gas leaving the boiler or condensed as the gas cools.

In 1978 about 50 million tons of coal fly ash was produced and it is estimated that the increased consumption of coal will raise fly ash production to approximately 60 and 150 million tons per year by 1985 and 2000, respectively [1]. Only about 17 percent of the fly ash produced annually in the U.S. is presently being used and this largely for construction purposes. Nearly 40 million tons of fly ash per year is currently being transported to disposal sites.

The disposal of large amounts of coal fly ash is an environmental problem the seriousness of which is only now being recognized. The two principal reasons for environmental concern are the entry of heavy metals from fly ash landfills into the soil and water supplies, and radiation from the naturally occurring radionuclides in the ash.

Fly ash particles, including the small weight fraction exhausted with the stack gases, contain measurable quantities of toxic elements. The key to the particles environmental and health effects lies not in the bulk composition of the particles but on their surface where readily transferable or extractable toxic components gather. Elements such as As, Cd, Tb, Se, and Zn are vaporized during combustion of the coal and are then adsorbed onto the surface of the cooling ash particles. The concentration of toxic metals on the ash particle surfaces can be as much as 100 times that in the coal [2].

The particles which escape through the stack gas cleanup systems are in the size range (1 to 10 μm in diameter) that can be respirated into the lungs. In addition, these show the highest concentration of toxic metals, have the highest rates of atmospheric mobilities, and have the greatest tendency to be deposited in the pulmonary and bronchial regions of the respiratory system [3].

The fly ash particles that are removed by the stack gas cleanup systems also lead to environmental problems because of surface-sorbed toxic metals. Contact between this ash and water in landfills can solubilize small amounts of the toxic elements which are then taken up in the soil or enter the surface water or ground water systems. An increase in pH

makes the metals more soluble. Consequently, the most hazardous fly ashes are acidic and this property has been found to be a function of the iron oxide content.

Toxic metals solubility determinations have been made using both lysimeters and leaching procedures [4]. Tests using lysimeters show a larger amount of material dissolved and give a higher toxic metal concentration in the water. Thus a greater potential for water quality degradation exists when the water percolates through a bed of ash rather than being mixed with the ash as in a pond.

The natural radioactivity of coal ashes can also be the source of health hazards. Even though modern stack gas cleaning methods, such as cyclones and electrostatic precipitators, recover over 98% of the particulate matter, a large power station will exhaust several thousand tons of ash into the atmosphere each year. Based on the concentration of particles in the stack gas and the hygienic effect of the natural radionuclides in the ash particles, it has been shown that the radioactivity hazard to human health from a coal-fueled power station is at least 1,000 times greater than the radioactivity emanating from an equivalent nuclear power plant [5]. The ash removed from the stack gas for disposal also contains radionuclides and in many cases the radiation level will exceed the limits set by the U.S. Environmental Protection Agency (EPA) to determine which solid substances are radioactively hazardous [6].

The above potential hazards of toxicity and radioactivity to health and the environment give a sense of urgency to proper management of fly ash recovery and disposal. The 1976 Resource Conservation and Recovery Act (RCRA) deals with the management of solid and hazardous wastes and encourages energy and resource recovery. Regulations promulgated in January 1980 by EPA under RCRA temporarily exempt coal combustion wastes from classification as solid hazardous materials. This status can be changed any time in the following 24 months. In the meantime, increased efforts are being made to better understand the hazards of fly ash and to develop alternate means for its disposal.

Research at the Ames Laboratory has focused on fly ash utilization as an alternative to disposal. Two processes are being developed to extract metals from the ash and to provide uses for the residues. The first is the Ames Lime-Soda Sinter Process in which a mixture of fly ash, limestone, and soda ash is sintered to produce a clinker from which aluminates are extracted using a dilute sodium carbonate solution. Recoveries of alumina as high as 90% are obtained from both bituminous and subbituminous coal fly ashes. The residue is primarily calcium silicate which shows promise as a raw material for the manufacture of Portland cement.

The second recovery method involves the Ames HiChlor Process in which the ash is chlorinated at a high temperature in the presence of a reductant in a fixed or fluidized bed reactor. Several metals are recovered as volatile

chlorides. Yields are influenced by the characteristics of the fly ash but are usually 70% or better for the aluminum, iron, and titanium in the ash.

Ash feed preparation for both processes includes the magnetic separation of an iron-rich fraction which can be used as a heavy medium material for coal or ore beneficiation, or as an iron ore. It is expected that at least one of the processes will work on other wastes such as fluidized bed combustion residue, coal gasification and liquefaction wastes, and limestone flue gas scrubber sludges.

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HEALTH IMPLICATIONS OF UNCONVENTIONAL ENERGY PRODUCTION AND USE

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EXTENDED ABSTRACT

INTRODUCTION

Options for space heating and cooling, and fuel production represented by the term "alternative energy technologies" are many and varied. All de-emphasize conventional electric power systems and most are highly decentralized. This very dispersed and variable nature encourages expanded use by families and communities wishing to reduce their energy expenditures, and utilities attempting to meet escalating demand but hampered by spiralling construction costs. Decentralized energy sources are considered important in controlling demand growth and reducing the need for central station construction ¹. Thus, it appears that all alternative technologies will undergo testing and development at an expanding rate in the near term. Prior to full-scale implementation, we consider it appropriate to present a current understanding of the occupational and public health and safety implications of these technologies. No energy source is completely benign when all aspects of its utilization are taken into account. Geothermal, biomass, solar, conservation, and synfuels options are evaluated.

Geothermal and Biomass Occupational exposure to hydrogen sulfide gas occurs near all geothermal sites and wherever organic matter decomposes anaerobically. Respiratory damage has occurred to laborers in geothermal fields and farm workers have been killed while employed near agitating liquid manure systems. However, the most frequent and severe reported injury to geothermal workers is dermal exposure to caustic sludges produced by SO₂ abatement systems.

Principal health and safety considerations of biomass pathways are directly related to the diffuse nature of solar energy fixation by photosynthesis and subsequent transfer to animal food chains. Since the potential fuel is in an unconcentrated form, cultivation, harvest and transport are necessarily labor-intensive. A significant potential for occupational injuries and fatalities exists. Of all biomass systems evaluated, direct burning of solid fuels presents the greatest public health risk. Data are presented to characterize the population at risk and the frequency and severity of injuries.

Solar Solar technologies considered are wind, ocean thermal gradients, passive, photovoltaic, satellite power systems, low and high temperature collectors, and central power stations. Tidal power is also analyzed. Most of the technologies are in developmental stages only.

*Operated by Union Carbide Corporation under contract number W-7405-eng 26 for the U. S. Department of Energy.

Although small experimental models or pilot plants are operating in some cases, no actual estimates of health risks incurred during operation or disposal are available. The toxicology of materials used will be discussed, as well as potential hazards during manufacture and use. Health risks for solar technologies, based on estimates from related technologies, will be reviewed.

Unique hazards associated with solar energy include occupational exposures to Cd, Ga, and Si during manufacture of photovoltaic cells, and exposure to microwaves during development and operation of a satellite power system. Public health exposures to indoor air pollutants may increase in weatherized homes that are passively heated and cooled.

Conservation and Synfuels The construction of tightly-insulated dwellings and weatherization of older buildings reduces flow of outside air into home circulation systems. As a result, home atmospheres may contain NO_x, formaldehyde, and other compounds in concentrations greater than recommended air pollution standards. Sources and implications of chronic exposures will be discussed.

Potential occupational hazards during production of synfuels from coal, oil shale and tar sands include dermal and inhalation exposures to carcinogens, teratogens, and caustic agents. Hydrogen sulfide gas evolution was a major problem to Swedish oil shale workers during World War II [2]. The epidemiologic history of synfuels workers is reviewed and mitigation strategies for future development are recommended.

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A COMPARISON OF ENVIRONMENTAL ISSUES RELATED TO DEVELOPMENT OF
SMALL HYDROPOWER RESOURCES AT NEW VERSUS EXISTING SITES

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EXTENDED ABSTRACT

INTRODUCTION

Small hydroelectric facilities are defined as those projects that will have a capacity of < 25 MW. It has been estimated that there are 4,979 sites in the United States with small dams that could be retrofitted to generate 25×10^3 GWH annually. The energy potentially available from construction of new dams at 3,029 undeveloped sites has been estimated to be 52×10^3 GWH annually [2]. Although current interests are directed toward development of small hydro resources at sites with existing dams, the potentially greater energy available at undeveloped sites may receive increased attention in the future as the United States strives for energy independence. In this paper we compare the environmental impacts of rehabilitating existing dams with those of constructing new dams at small hydro sites. Our discussion focuses on the ecological consequences of these two types of development.

ANALYSIS

The construction of new dam/impoundment systems results in one primary ecological concern not generally associated with the retrofit of existing dams, namely the impoundment of flowing water (riverine) ecosystems and flooding of associated terrestrial landscapes. When a flowing water ecosystem is impounded, the depth, velocity, and residence time of water are modified. As a result, riverine biological habitats, temperature regimes, nutrient cycles, and water quality can be altered. These physical and chemical alterations can cause replacement of typical riverine biotic communities by those that are more characteristic of non-flowing environments. The creation of an impoundment also inundates the terrestrial landscape. Previous land use (agriculture, forestry, wildlife, etc.) of the inundated area is lost and a new shoreline is formed. Finally, new dam/impoundment construction can alter the riverine ecosystem (tailwater) below a dam. The extent of this alteration depends on the characteristics of the impoundment and the location of the discharge to the river below the dam [3]. The potential water use and land use conflicts discussed

above for new dam construction are most often severe, and the trade-offs are not easily mitigated or mediated.

Several additional ecological issues are of concern for both new dam construction projects and projects where existing dams are to be retrofitted for hydroelectric generation. General areas of concern for both types of development include (1) blockage of fish migration routes, (2) water level fluctuations in the reservoir and tailwater, (3) water quality changes in reservoirs and tailwaters, (4) instream flow requirements, (5) dredging and dredged material disposal, and (6) threatened or endangered species [4]. The physical presence of a dam can be a barrier to upstream fish migrations. Techniques are available to move fish around dams, but facilities must be carefully designed to ensure efficient passage of the target species [5]. Downstream migrating fish may pass through turbines or over spillways causing direct and indirect fish mortality [6]. Mitigation measures to reduce this adverse impact are still being proposed and evaluated. Potential adverse impacts from water level fluctuation due to hydroelectric generation cycles can occur in both reservoirs and tailwaters [7]. Impacts are most severe at projects operated in a store-and-release mode (peaking plants). Although an obvious mitigation measure is to operate hydro projects in a run-of-the-river mode, this option has an economic burden related to the power demand curve. Water quality concerns due to hydroelectric operation are complex and relate primarily to reservoir stratification, temperature and oxygen distribution, nutrient cycles, land use patterns in the watershed, and location of reservoir discharge [3]. Mitigation proposed for water quality concerns usually includes multilevel outlet structures at the dam. However, considerable research is necessary to specify release patterns through multilevel outlets that will satisfy water quality objectives. Maintenance of instream flow to protect fish and wildlife is a major issue affecting hydroelectric development. The problem reduces to (1) the current "state of the art" for specifying instream flows below hydro projects, and (2) the economic penalty associated with meeting the specified flow requirements. The potential adverse impacts resulting from dredging and dredged material disposal at hydroelectric projects has been recently reviewed [8]. Although adequate procedures currently exist to mitigate most impacts related to dredging, the cost of this mitigation may be prohibitively high. All of the issues mentioned previously can affect endangered or threatened species associated with hydroelectric projects. The verified presence of an endangered species and/or the existence of critical habitat for that species can preclude development if such development or operation of the project will adversely affect either the species or its habitat [9].

The potential significance of environmental issues associated with both new dam construction and rehabilitation of existing dams must be evaluated on a project-specific basis. Both adverse and beneficial impacts will be

a function of project design and the existing environment that will be altered. We emphasize that early awareness of potential environmental issues increases the possibility that impacts can be minimized and/or mitigated and environmental conflicts can be successfully mediated.

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THE ENVIRONMENTAL AND POLITICAL POLICIES IN LATINAMERICA

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INTRODUCTION

INDERENA by Presidential Decree No. 113 of January 26, 1976 entitled "Restructure of the Agricultural and animal husbandry Sector" (Sector Agropecuario) has as a national policy the protection of the natural environment. INDERENA thus cooperates in the coordination and control of the execution of environmental policy with other related agencies in Colombia or neighboring countries of Latin America.

That it is the continuing policy necessary for Latin America to create and maintain conditions under which men and nature can coexist in productive harmony and fulfill the social, economic, and other requirements of present and future generations of Neotropical regions.

In our country like other neighboring countries of Neotropical regions we are conscient about the profound impact of man's activity on the interrelations of all components of the natural environment, particularly the great influences of population growth, high-density urbanization, industrial expansion, natural resources exploitation like forestry, soils, water, fishes, fauna, flora, landscape etc. (See Fig. 1), management of ecosystems and new and expanding technological advances and permanent heed for maintaining environmental quality to the overall welfare and development of man.

It seems obvious and thence necessary that any experience about Protection, Control and management planning of Natural Renewable Resources and the Environment Should be Shared among the Latin American countries.

Accordingly it is a permanent obligation for the policy of INDERENA to use all practicable means and legal provisions including financial and technical assistance, in cooperation with institutions, state and local governments, international agencies and other concerned public and private national or international organizations.

These actions should be carried on in a manner calculated to foster and promote the general welfare, to create and maintain conditions under which man and nature can coexist in productive harmony and fulfill the social, economic, and other requirements of present and future generations of Latin Americans.

OBJECTIVES

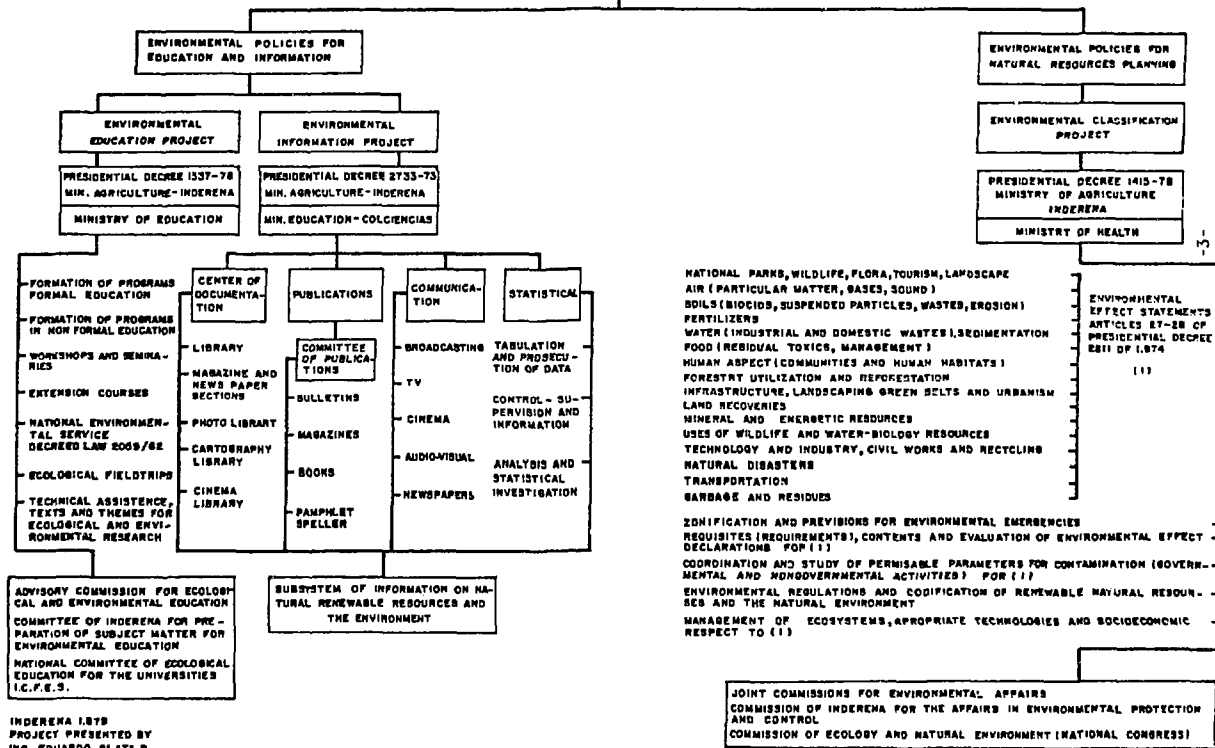
The basic objective of INDERENA'S Project on Protection Control of Natural Renewable Resources and the Environment is to develop and implement a PLAN OF ACTION for education, management of natural environmental resources and environmental information services for the Republic of Colombia that also could give support to similar efforts carried on by neighboring countries.

We believe that it is an urgent requirement to fulfill the common necessities and ideals in terms of the protection, conservation and sustained use of our natural renewable resources and environmental qualities, to establish an international Committee for the Defense of our living resources.

This committee would act as an agency for the coordination of research and legal actions directed towards our natural heritage, superb and irreplaceable, but increasingly endangered, and its future permanent use for human welfare.

PLAN OF ENVIRONMENTAL ACTION
INDERENA
PRESIDENTIAL DECREE 2811 OF 1974
PRESIDENTIAL DECREE 133 OF 1976

EPR



INDERENA 1878
PROJECT PRESENTED BY
ING. EDUARDO PLATA R.

ENVIRONMENTAL STUDIES ON METHANE PRODUCTION BY ANAEROBIC DIGESTION OF MUNICIPAL WASTES

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INTRODUCTION

Material and energy recovery from municipal wastes have a dual payoff in resource conservation and in reducing environmental pollution. One of the wide range of energy technologies being investigated is anaerobic digestion of municipal wastes. A proof-of-concept plant is being operated by Waste Management Inc. at Pompano Beach, Florida. This 100 ton/day plant is expected to provide data regarding economic and environmental viability of the anaerobic digestion process. The process involves shredding and air classification of the light fraction of municipal wastes followed by digestion and vacuum filtering of digested sludge. The filtrate is usually recycled. The filter cake is disposed in a landfill. This paper presents the results of an ongoing characterization and environmental program.

METHODOLOGY

A detailed description of the technical approach has been presented by Sengupta et al [1]. The approach consists of physical, chemical and biological characterization of all inputs and outputs at the plant. Analyses for major, minor and trace compounds are being conducted with particular concern for regulatory standards, the EPA priority pollutant list and known toxic substances. A significant part of the effort relates to development of predictive capability for pollutant transport. Fig.1 shows the schematic of the plant and sampling locations.

RESULTS

The plant has suffered numerous mechanical set backs and the data collected represents in general nonstable operating conditions. Walter [2] summarized the operational history of the plant. However, a data base extending over the period of August 1978 to August 1980 has been collected.

Gas Quality

Samples of the digester process gas have been analysed using gas chromatographic (GC), mass spectrographic (MS), non-dispersive infrared (NDIR), and electrochemical instrumentation. Direct monitoring of H_2S was performed at the site using an Ecolyzer. Grab samples were collected in purged glass bulbs and Tedlar bags for GC analysis in Miami. Results for unstable lower mesophilic (30°-40°C) digester conditions with the plant processing at 15 per cent of its design capacity revealed a gas quality similar to that in bench

tests and in landfills, De Renzo [3] and Lockman et al [4]. Methane (CH_4) levels were found to vary significantly about an average value of 55 per cent. Carbon dioxide (CO_2) levels were approximately 45%. Carbon monoxide (CO) was observed at levels up to 100 ppm during the first year of plant operation but was not observed the second year. Hydrogen sulfide (H_2S) has fluctuated considerably between zero and several hundred ppm because of air leaks in the digester seal. It is apparent, however, that the H_2S levels were less than 100 ppm during the second year of operation. Ammonia (NH_3) was detected at relatively high levels of 1500-1800 ppm this past year, probably as a result of the recent addition of sewage sludge to the system. Ethane (C_2H_6) and higher hydrocarbons have been sporadically observed at low ppm levels. Vinyl chloride, trichloroethylene, and tetrachloroethylene were detected at low ppb levels during the first year but were not detected the second year. Thus the major gaseous constituents that are of "potential" environmental concern under the stated digester conditions are H_2S and NH_3 . The results of a stable operation at mesophilic and thermophilic conditions as well as at higher loading capacities must await further testing.

Solid/Liquid Phase

Samples obtained from the various input and output streams of the plant have been analyzed for characterization in terms of the physical, chemical and biological parameters significant to land and water pollution. Comparison of the composition of the processed effluent of the plant with that of Dade County Discharge Standards for watercourses indicate that concentration of metals such as iron, zinc and copper are higher than that permitted by local discharge standards. Levels of BOD and total and fecal coliforms are also found to be in excess of the discharge limits. Although the processed effluent (filtrate) is presently being recirculated, adequate treatment of the effluent will be necessary if discharged into rivers or onto land in order to minimize the potential adverse effect on the environment. Experiments with activated sludge treatment of filtrate has resulted in 98 percent reduction of BOD levels and 78 percent reduction in COD levels. Bioaccumulation from treatment of heavy metals in the sludge may still present an environmental problem.

Leaching and Modelling

A fully three dimensional model has been developed to predict pollutant migration in soil-leachate systems. The chemical reactions between soil and leachate have been modelled using (1) the Lapidus Amundson linear model and (2) the Langmuir nonlinear model. The concept of dispersion as a lumped parameter has been used. The governing equations and boundary conditions have been nondimensionalised. Parametric studies have been done to determine the influence of the governing dimensionless parameters on pollutant attenuation by the soil.

Experiments have been conducted to determine the pollutant attenuation

capability of the soil beneath a specific landfill. Two types of soils have been studied. About ten cations and five anions have been investigated. The experimental data have been used in the mathematical model developed. Predictive studies regarding soil attenuation of the polluting cations and anions have been made. The relative mobilities of selected ions have been quantitatively measured in terms of the length of time taken by each ion to reach steady state under a fixed set of initial and boundary conditions. The relative mobility of an ion in a mixture as predicted by the Lapidus-Amundson model is different from that predicted by the Langmuir model.

CONCLUSIONS

1. In the output gas H_2S and NH_3 are at levels that might present environmental concern. Some gases from the EPA priority pollutant list have been identified at low ppb levels.
2. The filtrate if not completely recycled will need treatment prior to discharge to meet regulations.
3. Some of the pollutants identified in solid and liquid phases are in the EPA priority list.
4. Leaching experiments have indicated the complex nature of filtrate interaction with soil systems and the need for non-linear isotherms for correlating results of batch studies.

ACKNOWLEDGEMENT

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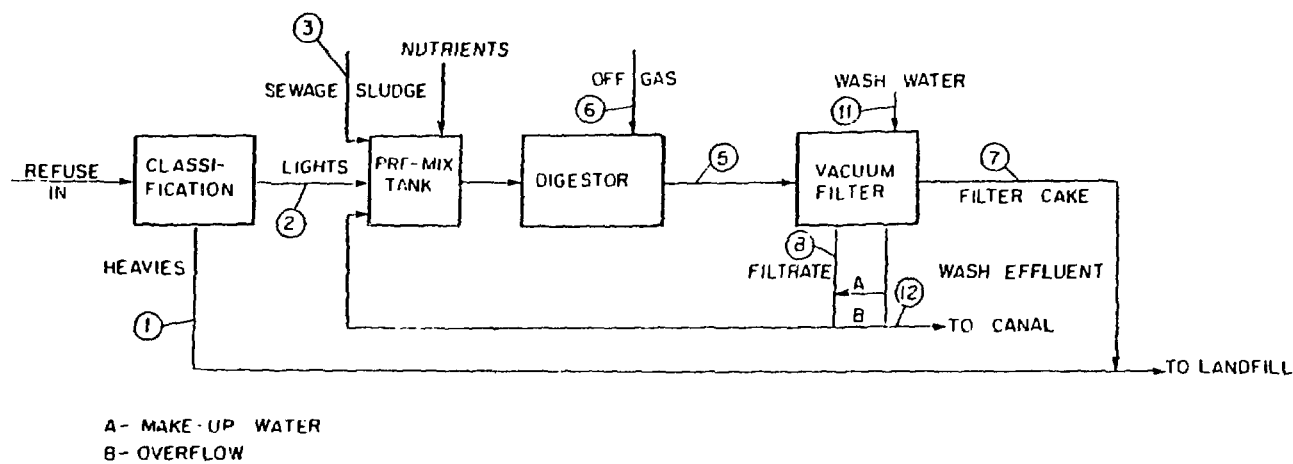


FIG. 1. Schematic Drawing of Pompano Beach Plant Showing Sampling Sites.

ENERGY CONSERVATION, ECOLOGICAL
STABILITY AND ENVIRONMENTAL QUALITY

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EXTENDED ABSTRACT

Energy is the lifeblood in the ecosystem structure and the human-social enterprise as well. The ecological stability in all levels of biosphere functions is a problem of environmental quality and ultimately of public health, economy and life-styles: The impact of energy availability, its use and abuse.

In the age of energy and natural resources scarcity with all sorts of disruptions in the industrial-economic fabric, the perilous energy crises and the threat of ecological breakdown, a hard new look and evaluation of energy use and conservation potential is urgently needed. The following scheme of pertinent questions is in order:

Energy and Mass Flow in the Ecosystems: Energy and the Determinants of Ecosystem Structure and Dynamics. Food Chain and Food Webs. How much is needed? How much is wasted? What is an optimum ecological efficiency within conservation planning systems analysis?

Energy and Mass Flow in the Human Environment: Human Ecosystem Adaptability. Environmental Stresses and Ecological Instability. Biological Control: Energy Conservation and the Re-establishment of a tolerable stable state.

Energy Conservation Planning: How much energy do we use and waste? How can energy use and waste be reduced in developed and developing countries within the context of enhancing ecological balance and economic-social growth?

THE IMPACT OF NEW SOURCE PERFORMANCE STANDARDS
ON ADVANCED INDUSTRIAL ENERGY TECHNOLOGY

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EXTENDED ABSTRACT

When Congress revised the requirements for New Source Performance Standards (NSPS) under the Clean Air Act Amendments of 1977, it defined a technological system of continuous emission reduction that would be an acceptable method of achieving the standard. This definition included not only post-combustion cleanup processes and pretreatment of fuels, but also a "technological process for production or operation by any source which is inherently lowpolluting or nonpolluting" (Sec. 111(a)(7)). This subsection was included to take account of emerging energy technologies, such as fluidized-bed combustion, and the combustion of coal-derived fuels, all of which have potentially reduced emissions compared to the direct combustion of fossil fuels.

When EPA came to revise NSPS for electric utility boilers in 1979, the concept of commercial demonstration permits was introduced, as a result of which certain innovative energy technologies were exempted from meeting the full standard (90% reduction of SO₂) for the first several thousand MW of capacity, as follows:

<u>Technology</u>	<u>Pollutant</u>	<u>Capacity (MWe)</u>	<u>Emissions Level</u>
Solvent Refined Coal	SO ₂	6,000 - 10,000	80% Reduction/ 1.2 lb/MMBtu
Atmospheric Fluidized Bed	SO ₂	400 - 3,000	85% Reduction
Pressurized Fluidized Bed	SO ₂	400 - 1,200	85% Reduction
Coal Liquefaction	NO _x	750 - 10,000	0.7 lb/MMBtu
	Maximum	15,000	

As EPA now begins revision of NSPS for industrial boilers, these and other issues need to be addressed again. Which energy technologies can be considered "adequately demonstrated" in the industrial sector, such that compliance with the full standard should be required? Which technologies have favorable emission characteristics, such that exemption from the full standard should be allowed while demonstration continues? What emission limitations should be expected from such technologies and for what initial capacity? How should cogeneration technology be treated under this standard?

This paper attempts to answer these questions, stressing the differences between the electric utility sector and the industrial sector, which might

make alternative standards or forms of standards preferable. A summary of the results follows:

Cogeneration is an energy technology that simultaneously conserves energy and reduces atmospheric emissions; NSPS that would encourage the use of cogeneration in industry would therefore be desirable. Relative emissions from different cogeneration systems and conventional boilers have been examined in some detail; and the most important case, that of SO₂ emissions from a coal-fired generating steam turbine compared to an isolated coal-fired industrial boiler and an electric utility component, is illustrated in Figs. 1 and 2.

SO₂ emissions from a cogenerating system are generally lower than the sum of the emissions from an isolated boiler, operating at the same emission limitation, and a utility emissions component, to produce the same delivered heat energy and electricity. A range of utility emissions is given in Figs. 1 and 2, from an oil-fired utility plant to an existing high-sulfur coal-fired plant. With high-sulfur coal as the industrial fuel, a case could be made for relaxing the removal requirement from 90% to 85% without significantly increasing emissions; and with low-sulfur coal, a relaxation from 70% to 50% removal seems environmentally sound. Uncontrolled combustion in small systems firing low-sulfur coal is even a possibility. Of course, at the industrial plant site, emissions would inevitably increase; and, therefore, if the plant location is close to a nonattainment or PSD Class I area and the utility plant is in a rural location, the option would not be environmentally desirable.

With respect to fluidized-bed combustion (FBC), there has been some, but not much, additional demonstration experience gathered since the development of NSPS for electric utility systems. However, it still appears that continuously high SO₂ removal efficiencies ($\geq 90\%$) have not been demonstrated over long periods of time under typical industrial operating conditions.

Significant energy and environmental benefits are possible from the introduction of FBC technology into the industrial sector, considering such items as the improved energy conversion efficiency, low NO_x emissions, and improved solid waste handling and disposal characteristics. A strong case can be made for relaxing the SO₂ control level requirement for FBC from 90% to 85% or 80%, in order to foster FBC applications in industry. In fact, because of the efficiency improvement, it is estimated that exemptions of approximately 6000 MW_t for 85% removal, or 3000 MW_t for 80% removal, could be permitted without any increase in SO₂ emissions by 1985. The NO_x emissions benefits would then be gained at no environmental cost.

The complete paper will discuss in more detail possible standards for cogeneration and fluidized-bed combustion systems, as well as appropriate levels for the combustion of coal-derived liquids and gases. A case will be made for active consideration of standards based on delivered energy (heat input) and standards taking into consideration multi-media environmental impacts.

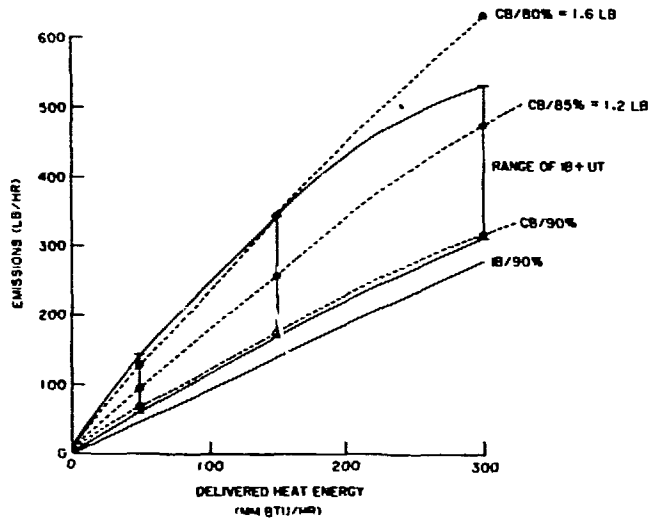


Fig. 1. Comparative Emissions with High-Sulfur Coal as the Industrial Fuel (CB=Cogenerating Boiler, IB=Isolated Boiler, UT=Utility)

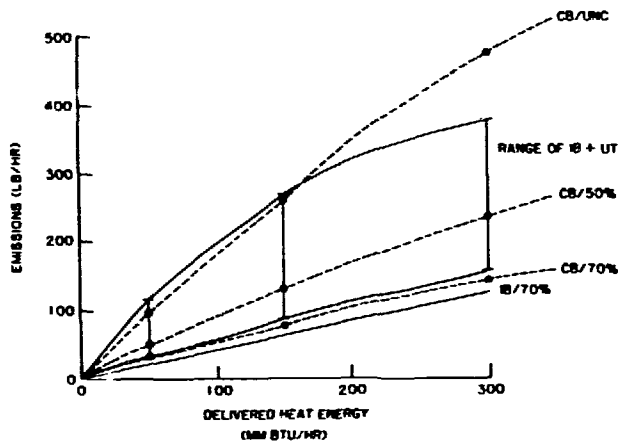


Fig. 2. Comparative Emissions with Low-Sulfur Coal as the Industrial Fuel (CB=Cogenerating Boiler, IB=Isolated Boiler, UT=Utility, UNC=Uncontrolled)

ENERGY, HELIUM AND THE FUTURE-II*

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EXTENDED ABSTRACT

The importance of helium as a critical resource material has long been recognized by the scientific community and more recently by the 1960 Congressional mandate to institute a long-range conservation program. The eventual termination of this program in 1973 has created since, a considerable controversy involving legal, political, economic, and institutional issues. Many study reports and discussion articles have been written concerning these issues as they relate to the past, present, and future needs for helium. A major study mandated by the Energy Reorganization Act of 1974 resulted in the publication in 1975 of the document, "The Energy-Related Applications of Helium," ERDA-13. This document contained a comprehensive review and analysis relating to helium resources and present and future supply/demand relationships with particular emphasis upon those helium-dependent, energy-related technologies projected to be implemented in the post-2000 year time period, e.g., fusion. Recommendations concerning the management of the federal helium program were made as a result of the study.

The subject of helium conservation was discussed previously at the First International Conference on Alternative Energy Sources held in 1977. An overview was presented covering the effects of policy then in existence upon the helium needs of the future. More specifically, the activities of the various groups within the public and private sectors directly concerned with helium usage and conservation were described.

A reexamination of the data base for the 1975 ERDA-13 document, "The Energy-Related Applications of Helium," has been completed, and the resulting information is presented in this paper. In particular, the technical data base has been updated and enlarged, and the various socio-economic, legislative, and legal factors associated with helium conservation issues have been reviewed and reevaluated in terms of developments occurring within the past five years. A summary of the data obtained follows.

Helium exists in conventional natural gas used as fuel, but its concentration varies from field to field. The total U.S. natural gas-derived helium resource base (exclusive of unconventional resources) has been estimated by the U.S. Bureau of Mines (BOM) to be ~718 billion cubic feet

*Work done under the auspices of the U. S. Department of Energy.

**Consultant to the Los Alamos Scientific Laboratory.

(Bcf) as of 1978. This total has been reduced by ~25 Bcf as of January 1980. Sources other than the Bureau however, consider that agency's estimate to be somewhat optimistic. The BOM estimate of 718 Bcf of helium contained in natural gas must be further qualified, however. Of the total, 83% is depleting, 63% is undiscovered, and 75% is either subeconomic or undiscovered. Therefore, this nation cannot afford to be complacent about the magnitude of its remaining helium resources.

Barring the enactment of specific legislation now undergoing discussion in the 96th Congress (1979-1980), no action is contemplated by the federal government or the natural gas industry to recover helium either from the helium-rich fuel natural gas streams not already being exploited or from any helium-lean fuel natural gas streams.

Unconventional natural gas resources have also been examined as potential sources of helium. In general, it has been found that major uncertainties exist with respect to both natural gas and helium resources.

Helium exists in the atmosphere with a steady-state concentration of ~5 parts per million. Extraction from the atmosphere is possible but to do so will be much more costly than at present in terms of energy and dollars by a factor of several hundred.

Current total demand for the U.S. helium is about 1.1 Bcf/yr. Consumption is expected to reach a level of about 1.5-1.7 Bcf/yr in the year 2000 for such research and industrial uses as cryogenics, pressurization, welding, chromatography, breathing mixtures, and leak detection.

Major energy-related uses of helium are projected to be primarily in the area of advanced electric power technology. These uses are not expected to become substantial until well after the year 2000.

Several helium-dependant, energy-related technologies have been identified, which will require significant amounts of helium. The three most important are (a) superconducting power transmission lines (SPTL), (b) superconducting magnetic energy storage (SMES), and (c) magnetic confinement fusion reactors. Estimates of helium demand with time have been developed for these technologies.

Total U.S. helium production capacity, if all currently operating plants were in full production, is estimated at ~2.4 Bcf/yr for 1980. Supply now exceeds demand by a factor of approximately two with the excess being stored or vented.

Although the U.S. has been the major world source for helium in the past, foreign gas-field sources will assume more importance in the future.

A number of alternative separation methods for extracting helium from the atmosphere, helium-lean natural gases, and low-level outer space have been examined. At the present time, only the cryogenic and differential diffusion (membrane permeation) methods, although costly for very dilute systems, have both technical and economic viability.

A major fraction of the energy cost of helium extraction via the cryogenic method is found to reside in the mechanical work done in handling the carrier gas.

A review of past and recent estimates of the cost of extracting helium from the atmosphere, all corrected to 1980 dollars, suggests that a unit selling price of ~\$7000/Mcf appears to be a realistic cost for helium extraction from air in a single purpose plant. In terms of energy, the production of 1 Bcf/yr of helium from the atmosphere would require about 17% of the projected 1980 annual coal production or about 500 million barrels of oil.

Legislation is presently under consideration in the Congress with the avowed purpose of creating a new national conservation program. However, the indeterminacy of the supply/demand situation some 50 years from 1980 only serves to increase the difficulty of making a decision in this matter.

ENERGY, CAPACITY AND ECONOMIC EFFECTS
OF COGENERATION INTERFACED WITH
AN ELECTRICAL UTILITY SYSTEM

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EXTENDED ABSTRACT

The objective of this analysis is to estimate potential energy savings, capacity credits, and economic impacts of various arrangements for electrical power supply between utilities and cogenerators. The approach is to use a methodology similar to that used by utilities in their capacity planning investigations and in estimating generation costs for these systems.

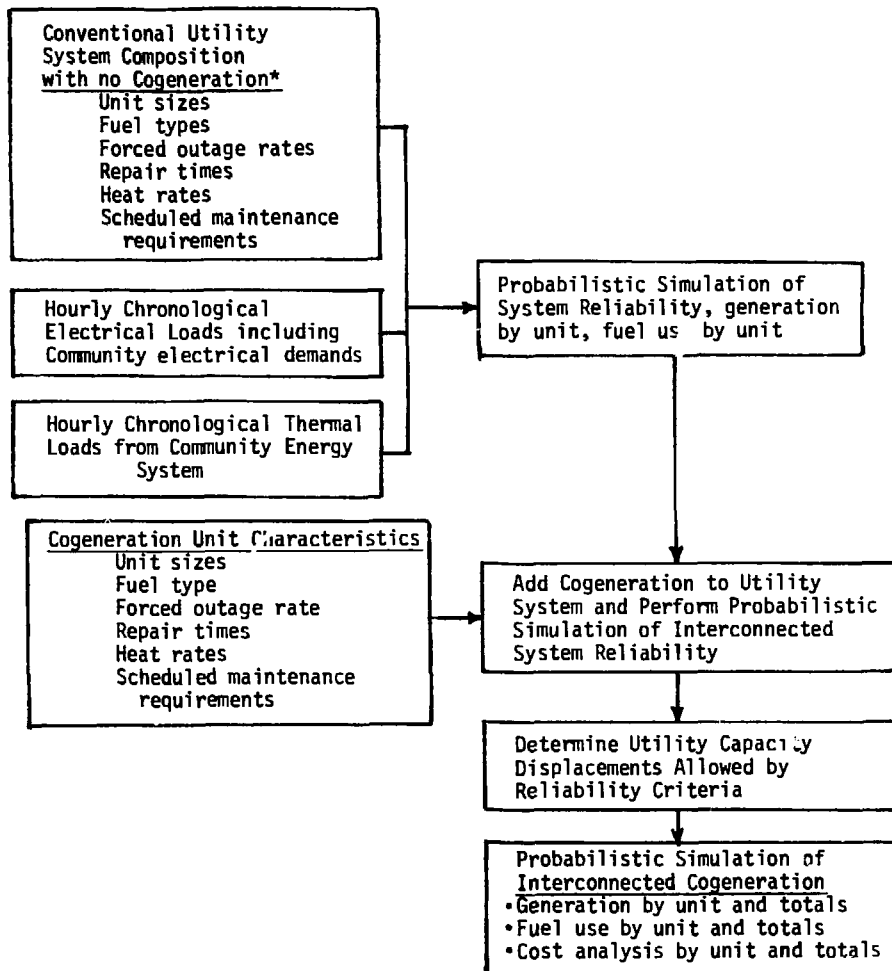
Cogeneration refers to the combined production of electrical and thermal energy. The combined process usually improves the overall conversion efficiency compared to separate energy sources. In recent years the conservation of scarce fuels (oil and natural gas) has been viewed as an especially important objective for cogeneration.

A major difficulty in the analysis of cogeneration is the dependence of energy and capacity impacts on specific utility and cogeneration characteristics. The number of utility generating units, their sizes, fuel types, and operating performance statistics affect the nature of cogeneration benefits. Design alternatives for combined electrical and thermal production similarly allow variations in unit sizes, fuel types, efficiencies and operating constraints. Load characteristics and correlations for electrical and thermal demands significantly influence the effectiveness of cogeneration. Dispatch priorities and energy transfer agreements between the utility and cogenerator add further complexity to the problem.

Figure 1 outlines the computational steps used to simulate interactions between cogeneration and the utility. Chronological load data is combined with a performance model to determine overall conversion efficiency for cogeneration as a function of thermal and electrical outputs. Backup arrangements with the utility (in case of failures) are treated in the process of dispatching cogeneration units.

RELCOMP (The Reliability and Cost Model for Electrical Generation Planning) is used to determine reliability levels and capacity credits for the utility system.¹ System reliability is determined from probabilistic treatment of forced outages, maintenance requirements and loads. Capacity credits are derived from reliability contributions of cogeneration to the utility. They refer to the amounts of capacity that can be replaced by cogeneration without reducing reliability levels below a predetermined value. Capacity displacements may take the form of delayed installations, plant cancellations, early plant retirements, or other changes in the utility's expansion.* The magnitude of these capacity credits are important inputs to the value analysis of cogeneration.

* Rigorous long-range expansion planning studies have not been performed. Ideally, a dynamic optimization analysis would be used to designate capacity credits.



* Conventional system includes separate thermal generators to supply community thermal demands.

Fig. 1. Overview of Utility System Integration Analysis for Cogeneration.

Plant-by-plant energy generation is determined in RELCOMP for fuel consumption comparisons. The production-cost portions of RELCOMP combine fixed and variable cost assumptions with plant commitments to determine integrated system costs. Comparative economics for each cogeneration case study are based on capital, fuel and operation & maintenance costs.

Initial case studies are based on cogeneration designs which were developed in studies of integrated community energy systems.² Both thermal and electrical demands are specified for the community system. An extraction turbine is used for cogeneration; both oil and coal fueling options are examined.

Two synthetic utility systems are tested for their fuel and reliability responses to cogeneration.³ One is representative of systems in the midwest with predominantly coal-fueled capacity. Nuclear and oil units make up most of the remaining capacity. The other system is primarily oil-fired capacity with smaller amounts of coal and nuclear sources.

Results show a high degree of sensitivity to the utility plant mix, cogenerator design and fuel, and the type of capacity displaced. The most favorable combination of conditions for cogeneration occurred when coal cogeneration was used to displace utility oil capacity. In terms of energy and dollar savings this afforded substantial scarce fuel savings. In the oil-based utility, cogeneration showed moderate economic advantages over conventional utility units. In a predominantly coal-fired utility the fuel and capacity credits from cogeneration were not large enough to offset higher capital costs (\$/kWe).

The sensitivity of cogeneration interface impacts to design variations and utility compositions will be displayed in the full length paper. Comparisons will focus on scarce fuel effects and combined system costs.

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COGENERATION/DISTRICT HEATING -
THE OPPORTUNITY AND THE CHALLENGE

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EXTENDED ABSTRACT

The Departments of Energy and Housing and Urban Development have undertaken a major new initiative to accelerate the implementation of district heating in cities throughout the United States. District heating is a system for the distribution of thermal energy from a central source to residential, commercial, and industrial users. A proposed National district heating program has the potential to conserve scarce fuels by (1) substituting alternative sources of energy for the oil and natural gas that are now burned in individual buildings, and (2) more efficiently utilizing existing energy sources through the use of cogeneration powerplants. Over 90 percent of the energy required for space and hot water heating in the United States is supplied by oil and natural gas. A district heating system not only can provide energy for space heating, industrial process heat, and hot water, it can also be used for cooling purposes by absorption chilling. Energy sources for district heating include coal, nuclear, industrial waste heat, solid wastes, geothermal reservoirs, and solar radiation.

In 1977, the Department of Energy initiated studies on the feasibility of using cogeneration/district heating in the Twin Cities (Minneapolis-St. Paul) area. In an electric-only plant, about 65 percent of the thermal energy is rejected to the environment through stack gas losses and the plant's cooling system. By utilizing most of the rejected heat, a cogeneration plant can operate at a fuel utilization efficiency approaching 85 percent. This requires some reduction in electricity output, but for each unit of electricity sacrificed, five to ten units of useful thermal energy are made available. The results of the Twin Cities study indicated that a 2600 megawatt thermal hot water district heating system appeared to be technically and economically feasible. If the regional system were implemented, about 50 million barrels of oil equivalent would be saved over the first 20 years of construction and operation. An additional 50 million barrels of oil would be saved over the next 10 years since the entire system would be in operation.

Additional studies have shown that if cogeneration/district heating were implemented on a National scale, a net savings of scarce fuels equivalent to 4½ quads per year by the year 2000 could be realized with a potential net energy savings of about 2½ quads.

Although district heating in the United States contributes only about one percent of the total U.S. demand for space heating, the use of district heating in Europe has increased enormously. This is in part due to Europe's historically higher energy prices and the more modern utilization of hot water instead of steam as the heat transport medium. Transport of steam is limited to a maximum distance of a few miles, whereas a hot water system can economically transport the energy 60-70 miles.

Hot water district heating provides a maximum degree of feasibility since such a distribution system is not tied to any single energy source. In addition, once the distribution network is established, there is no apparent reason why one could not change from one energy source to a different source, should circumstances change.

The use of district heating in the high density areas of our cities can serve as a major force to stem the rate of increasing energy costs in areas where those most unable to bear the higher costs of energy have traditionally lived.

A MICROPROCESSOR-BASED RESIDENTIAL HEATING CONTROLLER

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EXTENDED ABSTRACT

INTRODUCTION

One of the simplest and most popular methods of conserving energy in a residence is by lowering the thermostat setting during the heating season. Further savings can be realized by setting the thermostat even lower at night and during unoccupied periods. Using computer modelling of various setback strategies, Nelson and MacArthur [1] found that on a house insulated to R18, a 6°C setback for eight hours each night would save from 8.5% of gas in Minneapolis, to 10.7% in Atlanta. For greater night setbacks, clock thermostats are available which will change the thermostat setting at preset time, regardless of ambient conditions [2,3,4].

The timer will generally be set such that the house is warm at the wake-up time in the morning for the coldest day. This implies that on warmer mornings, the furnace will begin heating and maintain the house at the set temperature earlier than necessary, resulting in certain amount of wasted energy.

This paper describes an adaptive thermostat using a microprocessor that takes into account the ambient conditions dynamically in maintaining the temperature schedule inside the house. The major components of the system is an electronic controller which will allow the homeowner to define a weekly schedule of times and temperatures in the house to meet his comfort needs at minimum energy cost. The device calculates the time required to raise the temperature to a new level, for any given ambient temperature and starts the furnace so that the higher level is reached at the preset time. The paper also discusses the mathematical model, development of the control strategy and an algorithm, and preliminary economic evaluation of the adaptive thermostat system.

Conceptually, the operation of a clock thermostat and the adaptive thermostat may be visualized, for low and high given outside temperature, as shown in Figure 1.

In Figure 1(a), for the coldest ambient conditions, the two systems function identically. For warmer outside temperatures, Figure 1(b), the adaptive thermostat curve shifts to the right on the time axis resulting in the energy saving shown by shaded area.

Research work on this concept has been done by several groups, including Johnson and Wintr. at Colorado State University [5,6]. A team at Motorola Corporation is developing an adaptive thermostat for hot-water circulation heating systems [7].

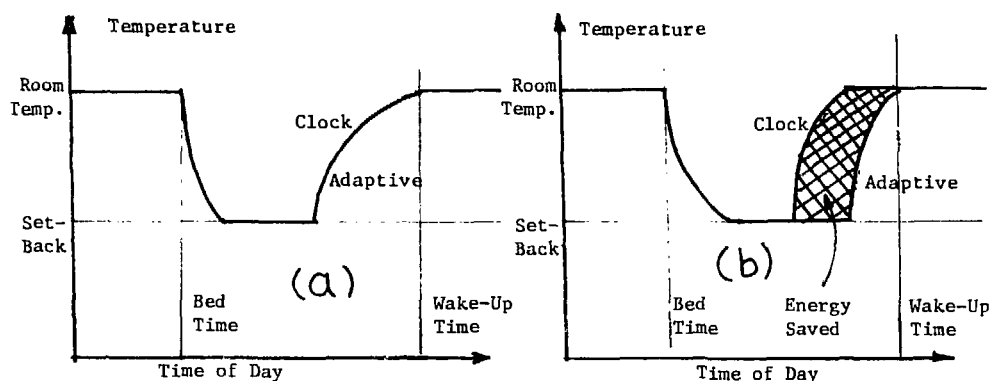


Figure 1: Performance of Clock and Adaptive Thermostats (a) Low Ambient Temp.
(b) High Ambient Temp.

The adaptive thermostat proposed in this paper uses inside and outside temperature measurements and a heat balance algorithm to calculate the time required to raise the inside temperature to a higher level. The controller will monitor the reaction of the inside temperature while the furnace is switched off or on to determine the heat loss and furnace performance factors of the individual house. Thus changing conditions inside the house, such as windows or doors left open or an operating woodstove, are accounted for when the furnace start time is calculated, and minimum energy will be consumed in raising the house temperature to a new level at the preset time.

MATHEMATICAL MODEL

The form of the house time-temperature transfer function can be derived from the heat balance equation of the house. Assuming that the thermal capacitance of the house structure and radiation effects are negligible and that the furnace is the only source of heat, the heat balance equation is written:

Furnace heat input = heat stored in air + conductive and convective heat losses.

$$K = MR_a \frac{dT_i}{dt} + \mu A (T_i - T_o) + \rho_i R_a C T_i - \rho_o R_a C T_o$$

where K = rate of heat input from furnace

M = air mass in house

R_a = air gas constant

μ = average thermal conductivity of outside surfaces

A = outside surface area of house

T_i = inside temperature

T_o = outside temperature

ρ_i = inside air density

ρ_o = outside air density

C = volume flow rate of infiltrating air.

Using Laplace transforms to solve this equation for T_i

$$T_i(t) = \frac{(\mu A + \rho_o R_a C) T_o + K}{\mu A + \rho_i R_a C} \left(1 - \exp \frac{-(\mu A + \rho_i R_a C)t}{MR_a} \right) + T_i(0) \exp \frac{-(\mu A + \rho_i R_a C)t}{MR_a}$$

which relates the inside temperature at any time t to the initial inside temperature at $t = 0$, the house and furnace constants, and the outside temperature.

Writing the time constant as $Z = \frac{\mu A + \rho_i R_a C}{MR_a}$

and the furnace ratio as $Y = \frac{K}{\mu A + \rho_i R_a C}$,

and considering $\frac{\mu A + \rho_o R_a C}{\mu A + \rho_i R_a C} \approx 1$, this equation reduces to

$$T_i(t) = (T_o + Y)(1 - \exp(-Zt)) + T_i(0) \exp(-Zt)$$

The time constant, Z and the furnace ratio Y can be experimentally found using the above equation. In fact, this is achieved by the thermostat automatically by measuring the temperatures T_i and T_o at different times. These values of Z and Y are used to solve for the time required to raise the inside temperature of the house from one level to another.

Thermostat software also includes provision for entering a weekly schedule of time-temperature pairs representing daily thermostat settings.

The thermostat has several types of displays, provisions for manual override and alarms for abnormal conditions.

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DESIGN AND PERFORMANCE OF D.C. CHOPPER CIRCUITS USED
WITH D.C. TRACTION MOTORS

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EXTENDED ABSTRACT

ALTHOUGH MANY APPARENTLY DIFFERENT TYPES OF D.C. CHOPPER CIRCUITS ARE DESCRIBED IN THE LITERATURE. A LITTLE DETAILS^{have} BEEN MADE FOR DESIGNING THE CIRCUITS. IN GENERAL, CHOPPER CIRCUITS COULD BE DEVIDED INTO CHOPPERS IN WHICH THE COMMUTATING CAPACITOR IS RECHARGED AT A RATE SUBSTANTIALLY DETERMINED BY THE MOTOR CURRENT AND THOSE WHICH ARE NOT.

IN THIS PAPER, A DESIGN FOR D.C. CHOPPER CIRCUITS IS PROPOSED. THE DESIGN OF A CHOPPER CIRCUIT BASICALLY INVOLVES THE CALCULATION OF THE VALUES OF THE COMMUTATION CIRCUIT COMPONENTS.

IN THE PAPER, THE DESIGN OF THREE TYPES OF CHOPPER CIRCUIT WERE CONSIDERED. THEY ARE THE BASIC CHOPPER CIRCUIT, THE RESONANT PULSE TURN-OFF CHOPPER CIRCUIT AND THE THREE-THYRISTOR CHOPPER CIRCUIT.

WITH THE INCREASING INTEREST IN D.C. CHOPPERS FOR TRACTION APPLICATIONS, THE DEVELOPMENT OF HIGH FREQUENCY OPERATION CIRCUITS REMAINS AS A MATTER OF GREAT IMPORTANCE. THIS IS MAINLY DUE TO THE FACT THAT THE SIZE, WEIGHT AND COST OF THE INPUT CAPACITOR FILTER CAN BE REDUCED.

THE LAST CIRCUIT HAS ALSO THE ABILITY TO RECOVER FROM A COMMUTATION FAILURE AND PROVIDE A CHECK ON THE COMMUTATION CIRCUIT INCREASING RELIABILITY AND SAFETY.

- 710 -

IN THIS PAPER, FURTHER STUDY OF THE THREE-THYRISTOR CHOPPER CIRCUIT USING SUPPLY SIDE COMMUTATION HAS ALSO BEEN DESCRIBED AND THE ADVANTAGES AND DISADVANTAGES OF THIS CIRCUIT HAS BEEN INDICATED.

THE CYCLE OF OPERATION HAS BEEN DEVIDED INTO FOUR SEPARATE MODES. A DETAILED STUDY HAS BEEN CONSIDERED FOR THE ANALYSIS. AN EXPRESSION FOR THE OVER CHARGE VOLTAGE ON COMMUTATION CAPACITOR ALSO HAS BEEN OBTAINED.

A USFUL DISCUSSION CONCERNING THE DESIGN AND PERFORMANCE OF THE THREE TYPES OF CHOPPER CIRCUIT WERE ALSO PRESENTED.

MATHEMATICAL MODEL FOR THE BRIDGE-TYPE
AUXILIARY IMPULSE COMMUTATED
POWER INVERTER

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Present efforts in the path of research and development with respect to direct static alternative energy devices utilized in the industry, utility as well as communications, such as conventional storage batteries, hydrogen fuel cells, solar cells, redox storage batteries and bio-electrochemical cells, etc., point to a serious problem centered on their operational compatibility with respect to the attached AC power inverter.

Parameters of compatibility regarding the power inverter of the solid state type include optimum level of input DC voltage, peak power handling capability, efficiency and weight-cost factor.

Present research data point to the bridge-type auxiliary impulse commutated inverter as the most promising mode in regard of its performance of DC-AC power inversion. Such type of inverter demonstrated an optimum operation around an input DC voltage of $2.6 \text{ KV} < E_{dc} < 2 \text{ KV}$, 1.70 KA of current level, and with the number of interconnected inverter modules closely dependent on the total MW capacity and DC input voltage.

This paper undertakes the task of presenting detailed mathematical and analytical picture for the auxiliary impulse commutated power inverter through the development of mathematical model and then with dynamic representation in the complex frequency domain.

The mathematical model is represented by a set of integro-differential equations as well as their total solutions which set optimum criteria of inverter operation with regard to terminal input DC voltage, peak power handling limit, efficiency and a normalized weight-cost factor. Also a developed criterion sets variable constraints on the number of interconnected inverter modules with respect to DC input voltage and over-all power levels for maximum efficiency and weight factor. In the mathematical picture established, unique conditions have been derived under which the auxiliary impulse bridge-type inverter can offer compatible operation with an inter-connection of other static power devices, when the DC input voltage is below the present recognized attainable level of 2 KV and beyond 2.6 KV.

Then from the mathematical analytical set up already secured, dynamic model in the complex frequency domain is established for this type of solid state inverter correlating the AC output with respect to the input DC voltage level. The dynamic model set reliable conditional modes of operations for stable, as well as unstable, modes of commutations in terms of number of inter-connected modules, individual peak power limit, volt-ampere characteristics and range of expected efficiencies.

Both the mathematical as well as the dynamic models identified the effects of non-linearity regimes within the volt-ampere characteristics of the bridge-type inverter, especially at a relatively high input DC voltage level on the total steady state and transient time responses.

Mathematical model of the auxiliary impulse inverter is expressed below:

$$U_L(s) = \frac{1}{2} E_d(s) - \frac{E_c(t_1)}{s} - \frac{I_L(s)}{G(s)} - I_L(t_1) \quad (1)$$

where

$U_L(s)$, $I_L(s)$ are the transform of output voltage and current respectively;

$E_d(s)$ is the transform of the input voltage;

t_1 is the delay time between gating of the main SCR and the auxiliary SCR;

And the total time response in the constant region of SCR switching:

$$U_L(t) = \left[\frac{1}{2} E U_{-1}(t) - 1.70 L U_o(t) - E_c(t_1) U_{-1}(t) \right] - R \sin \omega t + \left(\frac{1}{\omega C} - \frac{R\omega L}{C} \right) \cos \omega t - \frac{1}{\omega C} \quad (2)$$

Results presented in this paper are centered on the steady-state and the dynamic analysis for the utilization of the bridge-type auxiliary impulse inverter with other static electric power devices for the ultimate goal of securing reliable, efficient and optimum processes of DC-AC inversion.

Also comprehensive analysis of characteristics is derived that will open the way for total utilization of the bridge-type auxiliary impulse inverter over unlimited range of DC input voltage including that below 2 KV and beyond 2.6 KV. Such expansion of operational input voltage will enable all kinds of static DC-generators to be inter-connected in any type of inter-connected combination and then ultimately to the bridge-type inverter for the delivery of the required AC power output.

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HISTORY OF WIND ENERGY UTILIZATION

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EXTENDED ABSTRACT

INTRODUCTION

Wind, defined primarily as air in motion, is a factor constantly contributing to the earth's environment. Depending upon the nature of the climate and topography, man has made use of the wind, protected himself from it or does both according to the season or terrain.

This paper will discuss the nature of wind, make a survey of the history of wind energy utilization and try to project current utilization trends into possible realized potentials.

NATURE OF WIND

Global Wind Systems The three forces governing global air movement – pressure gradient, Coriolis and frictional – have to be considered for successful harnessing of wind energy. Pressure gradient causes air movement by atmospheric pressure differences (*i.e.*, as equatorial air rises it causes an increase in high altitude air density, while the polar air sinks and causes an increase in low altitude air density). The Coriolis force is the action of the earth's rotation upon the air currents set up by the pressure gradient (*i.e.*, doldrums and tradewinds). Frictional forces, caused by velocity of the air and irregularity of the terrain, affect flow patterns at higher altitudes. Frictional forces are affected by pressure gradient forces.

Local Wind Systems Global winds are very often influenced or even superceded by local winds, usually dependent on local topographical features. There are several categories of these local persistent winds: land and sea breezes, and anabatic, katabatic and valley winds. Land and sea breezes occur along coastlines. Differences in temperature between the land and sea during diurnal and nocturnal periods cause varying directions of air flow. Anabatic and katabatic winds occur over mountain slopes. Warm air rising up the slopes induces the upslope or anabatic flow during the day. Cool air descending down the slopes at night cause the downslope or katabatic winds. Winds in long narrow valleys tend to channel along the main axis of the valley, deviating as the valley turns and increasing in velocity as the valley narrows.

Microclimates Microclimates are small-scale weather conditions in a given location, determined by elevation, surrounding terrain, ground cover, and water surfaces. Further, configurations between buildings and / or landscaping play a role in the character of the microclimate. Building size and structure are factors as well.

HISTORY OF WIND ENERGY UTILIZATION

Wind energy utilization has affected mankind in various ways: (1) Sailboats, (2) Windmills (used for agricultural irrigation and grinding; pumping and draining water; production of electricity), (3) Architectural cooling systems.

Sailboats A multitude of wind-driven vessels have transported man and his needs around the world throughout recorded history. They have also expanded man's warfare capabilities. Ancient records of sailboats illustrate man's conquest over the forces of water and wind (Fig. 1&2). The Viking ships (Fig. 3) overcame the obstacle of transoceanic voyages. The Chinese junk (Fig. 4) has had a reputation for being the ultimate in aerodynamic efficiency.

Anton Flettner revolutionized sailboat design by replacing sails with two 50-foot high revolving cylinders (Fig. 5). The crossing of the Atlantic in 1925 with the ship *Baden Baden* at a speed averaging 9½ knots proved the seaworthiness of such a unique design. His investigations showed that wind pressures on a revolving cylinder are considerably greater than on a conventional sail. Three 60-foot cylinders were also tried, but unsatisfactory results kept this novel idea from being pursued.

The Dyna Experimental Ship of Germany (construction started 1975) is a prototype cargo sailing ship which can automatically set sails, rotate masts mechanically on their own axes and roll up the sails vertically into the mast along grooves in the yard. Then, the yard folds up with the sails tucked neatly away (Fig. 6).

Windmills Ancient Persian vertical axis windmills (c. 200 B.C.), which were used for grinding grain, spread throughout the Islamic world. Chinese mills of this type were in operation in the 16th century to evaporate seawater for salt production. Modern use of the vertical axis windmill has its efficiency increased with the *S-Rotor* by Savonius (1933).

Post mills appeared in Europe in the 12th century. This mill was able to rotate and face square into the wind at any quarter.

Tower mills were invented to allow only the upper part (which held the sails) to rotate (c. 14th century).

Hollow-post mills, of Low Countries invention (15th century), enabled the drainage of that region to reclaim the land. Later on, this type of mill was also responsible for pumping in salt evaporation beds, grinding grain and wind-driven sawmills.

Windmills continued to develop greater utilization of wind energy. Some examples to be studied in detail are: Meikle's "spring sail" (1772); Lee's "fantail" (1775); Mead's centrifugal governing device (1787); Hooper's "roller blind" (1789); Cubitt's "patent sails" (1807); Catchpole's "air brakes" (1860); Darrieus' three-blade airfoil experiments (1920); Decker's airfoils (1927); and Savonius' "rotor" (1933).

La Cour's Danish mill (1890) was the first mill to produce electrical power from wind energy. Crimean versions also provided electrical power with a three-bladed airfoil (1931). Most notably, Putnam's twin-bladed airfoil at Grandpa's Knob, Rutland, Vermont, was started in 1940 for electrical production. The best generator of wind energy in 1955 was the three-bladed variety birthed by Danish inventor, J. Juul.

Recent American endeavors in wind energy have yielded huge electrical-producing generators or turbines in Sandusky, Ohio; Clayton, NM; Culebre, PR; Block Island, RI; and Boone, NC. Other contributions have been Sweeney's "sailing" and Gillette's "Venturi ducted wind dynamo."

Architectural Cooling Systems Overheating of buildings has been reduced throughout history by careful application of wind energy and air flow principles. Notably, for at least the past 500 years, *Bad-girs*, or air scoops, in Pakistan have collected prevailing, continuous afternoon cooling breezes to ventilate each room in the entire dwelling (temperature drops from 120° F to 95° is not unusual). Windtower houses in Dubai, United Arab Emirates, circulate cool air throughout the building night and day. Vernacular architecture in India, Samoan Islands and the Caribbean have engineered remarkable answers to building overheating problems.

Most recently (1980), homes built by A. Bowen, *et al.*, for fishermen in the extremely arid southern region of Egypt provide a comfortable living environment by evaporative cooling. This system combines wind movement through exterior wall openings with condensation formed in the rock-filled hollow wall cavity above the wall openings. The condensation forms droplets which fall through the openings. Air movement causes evaporative cooling to take place.

FUTURE REALIZED POTENTIALS

Present trends in wind energy utilization research and development may lead to: fleets of sail-assisted cargo ships, huge floating dynamos anchored offshore (as suggested by Heronemus' 1972 proposal), large-scale vertical axis Darrieus rotors (180 meter diameter) for wind turbines on land, icosahedron-supported Darrieus rotors on tall buildings and water towers, 250-foot high towers with six Darrieus rotors, Vortex towers to catch omnidirectional winds and turn them into torando-like wind forces (e. g., Sforza's "Vortex Augmenter" and Yen's "Torando Wind Turbine").

In buildings, large vertical-axis wind turbines may supply enough converted mechanical energy to run all the appliances in the home (air compression by turbine rotation could drive piston-like energy-conversion systems).

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Figure 1 Sailboat illustration in Egyptian rock carving (c. 3500 BC)

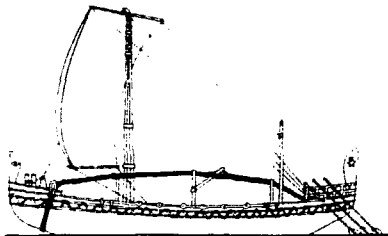


Figure 2 Pharaoh Sahure's sailboat (c. 2400 BC)

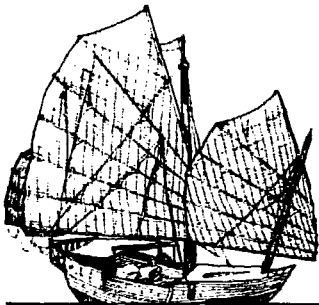


Figure 4 Chinese Junk (c. 9th century AD)

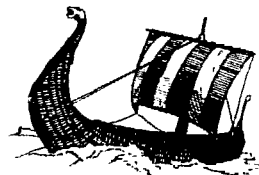


Figure 3 Viking ship, Gokstad, (c. 8th century AD)

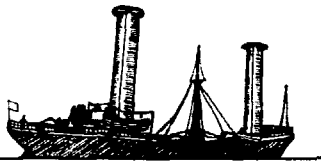


Figure 5 Flettner's Rotor Ship (1924)



Figure 6 The Dynast (1975)

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EFFECT OF SITE WIND CHARACTERISTICS
ON ENERGY PRODUCTION

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EXTENDED ABSTRACT

The decision to purchase a wind machine, large or small, is usually based on the economic value of the machine to the user. Obviously, economic value is a strong function of machine performance evaluated at a particular site. When there is no direct experience with wind machines at or near a proposed installation, machine performance can be simulated using machine performance information (power output as a function of wind speed) and wind data representative of the site. This paper examines the sensitivity of performance computations to uncertainties in the wind characteristics. Two potential applications are examined - one in which the load to be serviced is constant in time and one in which the load has large diurnal fluctuations.

When the energy produced by a wind machine has constant value, independent of what time of the day or season it is produced, determination of economic value is fairly simple. It can be deduced from the average energy production and a leveled cost of energy model. Average energy production can be calculated from machine performance information and the probability density function (PDF) of the wind speed. A wide range of machine performance characteristics and PDFs were examined. It is shown that within an annual average wind speed range of four to eight m/s, estimates of average power output using the average wind speed at the site and a Rayleigh model for the PDF differ by no more than 20 percent from estimates made using the actual PDF. This uncertainty is about the same as the uncertainty that can be expected in estimating the performance of small wind machines from hourly averaged wind speeds.

The economic value of wind power in many applications may depend on the match between temporal variations in the load and temporal variations in machine output. The importance of load matching is examined by computing the fraction of the total energy consumption of a typical residence that could be satisfied by a small wind machine under a variety of wind conditions. A small residence has very large diurnal fluctuations in energy consumption, thus this aspect of the study concentrates on the match between the load and diurnal wind speed fluctuations.

Time series of hourly average power output spanning a three-month season were produced for two small machines. These machines have significantly different performance characteristics. Wind data were used from four actual sites having typical, but widely differing diurnal characteristics. To isolate the importance of load matching, the average wind speeds at the four sites were adjusted so that the seasonal average power production at each of the sites was the same. The results show the fraction of total energy consumption displaced by a wind machine to be very dependent on the degree of load matching. In some applications, the economic value of a wind machine may be more dependent on the diurnal characteristics of the wind at the site than on the average wind speed.

NEW ELEMENTS IN WIND ENERGY CONVERSION SITING

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EXTENDED ABSTRACT

The purpose of this investigation is to examine the parameters and their effect on the selection of a second and subsequent sites for the installation of wind turbines to be integrated into conventional electrical generating systems. Assuming no system storage (nor wind energy conversion dedicated storage) most of the benefits associated with wind power were thought to result from fuel savings.(1-4) More recently, however, based on wind energy generation reliability, conventional energy generation reliability and power grid load demand, analysis has shown that wind power electric generators can also replace conventional installed capacity (5-7). In the last few years a considerable number of electric power companies have conducted (or are currently conducting) meteorological surveys within the territorial boundaries of their grids to determine optimal sites for wind power installations. A number of electric power companies have so extensive grids that it is possible to find sites with widely different wind characteristics.

It is reasonable (and historically has been the case) that the first unit (or group of units) to be located at the site with the highest energy production potential. However, after some penetration has been achieved with installations at one site, subsequent installation sites should not necessarily be chosen for their maximum energy production potential alone. Indeed it is possible that the installed capacity displacement value to outweigh the fuel displacement worth. This is possible due to the fact that increased installed wind power has a low saturation limit for installed capacity displacement when it is

subject to the same wind characteristics. The cited (5-7) investigations have shown the importance and the impact of the reliability of the conventional generating capacity, the grid load features and the wind characteristics for a given site. Here the diversity of the sites available to a power grid is examined as a new element in wind energy conversion siting optimization. The meteorological data of two different sites have been examined and analyzed and a correlation coefficient has been derived which quantifies the site diversity. This correlation constitutes an additional element for an integrated examination of the totality of the available sites. Some topological features are examined which can contribute to site diversity. Coastal and mountain features as they affect the wind patterns and the seasonal and diurnal variations, enter as elements of the correlation coefficient.

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A UNIFIED SITE EVALUATION SYSTEM
FOR WIND ENERGY CONVERSION

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ABSTRACT

A unified detection/evaluation system is developed for evaluating sites that have potential for Wind Energy Conversion Systems (WECS) especially for the availability for generation of electricity.

The system is unified in that the detection device is coupled with an analog-digital recorder that provides automatic input into a computer which evaluates energy output from the measurements.

The paper deals with:

- The physical features of the structural supports and the measuring devices. A portable tower in collapsed state is trucked to the potential site and erected either from the truck using side stabilizers and guy wires or on a regular foundation. The different tower arrangements are compared with each other for practicality and cost. Anemometers and other weather measurement devices may also be mounted on top of the tower.
- The signal conversion systems and translation of data into a recorder. Special equipment is needed for generating digitalized electronic signals which are channeled into a recording device located at the base of the tower or at a nearby or remote location. This recording device furnishes direct input into a computer.
- Consideration of a potential site which refers to some other factors such as the annual frequency of tornadoes, hurricanes, seismic activities, precipitation, temperature variation, terrain effects, e.g., offshore vs inland, and interference with trees and buildings.
- The computer program which picks up its input from the recorder and calculates the wind energy output is

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developed for generic wind turbine generators. This program considers the system characteristics such as rated power, cut-in velocity, rated velocity, and cut-out velocity coupled with operating conditions such as system start-up, system cut-in, high wind cut-out, low wind cut-out and emergency cut-out. Those system characteristics and operating conditions are given by the manufacturers of the WECS. The system characteristics are input data for the evaluation of energy output of WECS.

- Calculation of power output. The wind velocity measurement curve is subdivided according to the velocity at which the power generation conditions change. This division is dependent upon the different system characteristics of the WECS under consideration.

The advantage of the WECS characteristics-dependent calculations compared with calculations using the Weibull distribution leads to a more accurate estimation of the site potential. Instead of calculations using wind speed averages and disregarding system parameters of wind machines, a continuous wind velocity measurement curve is used in connection with response characteristics of available WECS.

The program output may be also used for a comparison of the anticipated peak loads with the availability of wind power generated electricity and for a comparison of economics of building WECS or additional conventional fuel powered generators. When construction of a WECS is economically justified the program will serve for recommendation of the best system for given power requirements.

ESTIMATION OF WIND SYSTEM PERFORMANCE AND ECONOMICS
USING UNIT AVAILABILITY CRITERIA

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EXTENDED ABSTRACT

This paper describes a methodology for evaluating the impact of unit availability on the overall performance and costs of wind energy conversion systems (WECS). The WECS is modeled as a collection of wind turbines, possibly with backup energy sources (e.g., diesel generators or batteries), tied to a time-varying demand and a (randomly) variable wind resource. Each wind turbine is modeled as a series of subsystems. The reliability of a subsystem is given as a probability distribution of the time to failure for the subsystem. The parameters of this distribution are obtained either from the literature or by using fault tree techniques to combine estimates of component reliabilities. System performance is calculated using Monte Carlo simulation of system operation under various scenarios. The results of the simulation then can be used as input to an economic model which calculates the system life-cycle cost. The sensitivity of system performance and cost to different subsystem reliabilities, operating and maintenance policies, system configurations, and economic assumptions is illustrated in parametric studies. Specifically, these studies clearly demonstrate that unit availability exerts a large impact on WECS performance.

Previous evaluations of WECS performance have tended to focus on the relationship between performance and wind resource reliability, wind system configuration and operating procedures, or wind turbine efficiency. These studies have recognized the importance of unit availability, but extensive efforts to quantify unit availability and its impact on overall WECS performance and cost have not yet appeared.

As part of this study, a WECS performance and economics analysis package was developed. The two principal components of the package are WESP, which uses Monte Carlo simulation to estimate the expected output of a WECS; and WESC, which uses the output from WESP to calculate the present value of the WECS life-cycle costs.

The input to WESP is a model of WECS, specified by the user. The model is described by:

1. Number of wind turbines
2. Number of subsystems in each wind turbine
3. Rated power of wind turbines

4. Number and rated power of backup energy sources
5. Failure and repair distributions for wind turbine subsystems and backup energy sources
6. Length of time that system operates
7. System demand as a function of time
8. Wind velocity distribution

Each failure, repair, or wind velocity distribution can be one of the following parametric families:

1. Exponential
2. Normal
3. Lognormal
4. Gamma
5. Beta
6. Uniform
7. Weibull

For these functions, the user must supply the appropriate parameters. Alternately, the user may supply a tabular description of the cumulative probability function of a distribution.

Using the user-supplied input, WESP simulates the system operation over the desired period of time, and estimates the expected value and variance of the following performance measures:

1. Wind turbine unit availability
2. Backup energy sources unit availability
3. Wind turbine total energy output
4. Backup energy sources total energy output
5. Total demand shortfall
6. Total energy output in excess of demand

The performance results, along with the WECS model, are then used as input to the WESC program, which calculates system costs. Also needed as input are system economic parameters:

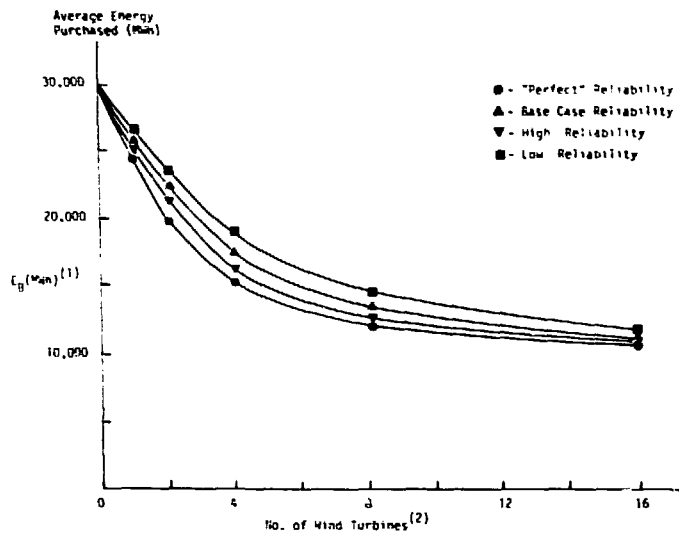
1. Capital cost of wind turbine and backup sources
2. Operating and maintenance costs for wind turbines and backup sources
3. Fuel cost for backup sources
4. Cost of demand shortfalls
5. Profit from sales of excess energy
6. Length of system life
7. Escalation rates for recurring costs
8. Discount rate

Using these data, WESC calculates the expected life-cycle cost of the WECS.

The WESP-WESC package was used to investigate the impact of subsystem reliability on overall WECS performance and cost. Each wind turbine was assumed to consist of four subsystems, each with exponentially distributed failure times. The system operation was simulated under four different levels of subsystem reliability, and the effect of additional wind turbines was examined. Figure 1 shows the results of this study over a 10,000 hour period when energy demand shortfalls due to wind resource or WECS hardware unavailability can be met by purchase from a utility grid. As the number of wind turbines included in the system is increased, the grid purchases required to make up for unmet demand decrease in all reliability cases. When a large number of wind turbines are being used (i.e., WECS capacity is much greater than demand), the energy purchased represents energy required during periods when the wind was unavailable. In this case, unit unavailability is unimportant because of system redundancy. The plateau (observed in Figure 1 around 10,000 - 13,000 MWh) where grid purchase reductions due to additional turbine are small, occur at lower wind turbine populations for those systems with better subsystem reliabilities. For example, the plateau is approached with eight turbines under the high reliability case, with twelve turbines under base case reliability, and with more than sixteen under the poor reliability case.

Figure 2 shows the effect of different subsystem reliabilities on cost savings for different wind turbine populations. It was assumed that excess energy generated by the WECS could be sold to a grid at the same unit price as energy purchased from the grid to meet demand shortfalls. For this reason, the curves of Figure 2 are increasing in spite of the increased expense of additional wind turbines. The cost savings realized from an additional turbine do decrease however, indicating decreasing marginal returns from increasing capacity.

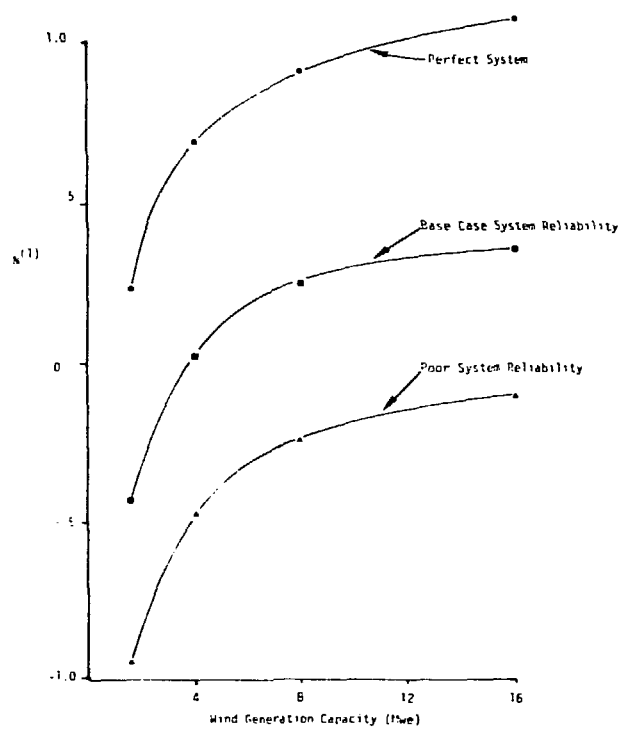
The results suggest that subsystem reliability impacts WECS performance and cost greatly. The failure of a utility or other operator of a WECS to solve reliability and maintainability problems risks a significant negative effect on system effectiveness. In addition, evaluative studies of WECS which ignore unit unavailability or assume overly optimistic levels of reliability may yield unrealistic results.



(1) Energy purchased from grid assuming constant 3 MW demand over 10^4 hours of operation

(2) Units with 2 Mwe rated output

Figure 1. Average Energy Purchased as a Function of Number of WECS for Various WECS Subsystem Reliabilities



(1) Fraction of capital cost recovered as savings to the user over plant lifetime assuming a plant life of 20 years

Figure 2. Cost Savings to User as a Function of Wind Generation Capacity for Several Reliability Scenarios.

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SESSION 2G

ECONOMICS AND POLICY I

ALTERNATE POLICY AND ENERGY SOURCE ECONOMICS

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EXTENDED ABSTRACT

A combination of factors has led to a world-wide power dilemma for mankind /1/. These include:

1. Substantially complete utilization of hydraulic potential of rivers close to major load centers.
2. Projected burn-up of existing, recoverable sources of petrofuels and coal, there being no replenishment.
3. Projected burn-up of existing recoverable nuclear fuels processed for use in fission reactors and the high cost of safely disposing of fission products produced.
4. Projected high cost of future breeder reactors and the contingent chemical plants for safely extracting plutonium for use in recycled fuel elements.
5. Lack of knowledge as to when, if ever, the egregious design problems of nuclear fusion will be solved.
6. The rapid approach to practical limits of electrical transmission line high voltage.
7. The extreme complexity, very high cost and impracticality of wide-spread use of superconductive electrical power transmission lines or storage devices.

Clearly a comprehensive policy that is widely understood, accepted and initiated, both here and abroad, is needed if man is to progress at his favorite breakneck pace using vast amounts of power along the way. Since America is the largest user of energy obtained by combustion of non-replenishable fuels, it makes sense that conversion to energy sources which can be recycled endlessly start here. If it is to be done well, it is important that we in America face up to the task and adopt a comprehensive energy program towards that end. As of now, America does not have such a policy.

Fortunately, there are a number of alternate energy sources which exist in abundance and/or can be recycled endlessly using existing technology. These include:

1. Heat tapped from geothermal sources
2. Velocity of major ocean currents
3. Velocity of winds
4. Solar energy (thermal or photo-voltaic conversion)
5. Combustion of methane recovered from garbage
6. Combustion of methane extracted from kelp
7. Combustion of ethanol from fermented grain
8. Combustion of methanol from destructively distilled wood
9. Combustion of electrolytic hydrogen

10. Velocity of tidal eages
11. Power from oceanic wave action
12. Hydro-electric power from large, remote sites
13. Standing temperature gradients in oceans, large lakes and large reservoirs
14. Heat from fusing atoms

This list does not include radiofrequency power received from photo-voltaic satellites, power plants based on standing differences in oceanic salinity or hydrogen dis-sociated from oxygen using non-electrolytic processes which seem to require considerable development and appear to be too expensive. Heat from fusing atoms was included due to the prime importance of solving, if possible, how to obtain unlimited power for millenia and the prevalence of low atomic weight fuel for fusion reactor plants.

Since there is no concise national guide for action, despite the number of available alternate sources of energy, one must attempt to determine the reasons why this is so. National policy makers seem to be confused to the point that the foundation of a national consensus on energy is impeded. Some leaders still believe we must be scared into believing there really is a world-wide energy crisis. Many of these make gloomy prognostications which tend to panic people into making the wrong moves instead of leading them to the right moves, which is tragic. In 1978 half the housing starts in America went for electrical heat due to the feeling that "there won't be any fuel gas starting next year." This was nihilistic and running in the wrong direction at top speed.

The metamorphosis of USAEC to ERDA to the USDOE has continuously rekindled a dilemma for this large organization. To paraphrase, a promulgator of alternate energy source ideas approaching this metamorphosing group at two-year intervals might encounter: "We are validating the nuclear option, who needs alternate energy sources?"; "We are reorganizing and who knows?"; and, "We are still reorganizing and who are you?" A USAEC Report to President Nixon repeatedly exhorted "Validate the nuclear option." Fission reactor plants would be the source of all of America's energy needs. At WHEC I, paper after paper described production of hydrogen using nuclear fission power. This was early in 1976 and some of us already saw such plants as obsolete and incapable of validation. Since then, the USDOE has discovered solar power and hydro power and converting fossil coal into liquid and gaseous fuels at an accelerated loss of coal reserves. To promote alternate energy sources does not preclude the full practical use of oil, natural gas, coal, coal tars and oily sands. Exploitation of all of these is indicated until alternate energy sources are in full use. After that the remaining fossil fuels can be used for the production of plastics and chemicals.

The "last vast sites for 60 Hz hydro power and what to do with it" syndrome is of interest. In Greenland there is a bowl with a bottom almost 400 meters below sea level. This bowl is filled with almost 3 KM of freshwater ice. The interior is dry and receives snow in winter. Surprisingly the east and west coasts are largely ice-free, and water run-off over nine months of each year is enormous and often exceeds the winter input [27]. There are few electric loads in Greenland, but its coasts could be lined with hydro-electric

plants accompanied by electrolyzers for dis-sociating water into its constituent gasses. The 99.5% electrolytically pure hydrogen and oxygen could be piped to a central terminal on each coast. The hydrogen could be combined with nitrogen (obtained cryogenically from air) at 1,000 atma pressure and 1000°K to form ammonia (NH₃) which could be shipped as a liquid. The oxygen could be liquefied for shipment. Hydrogen could be piped from the eastern terminal to Europe via Iceland, Scotland and England. Likewise it could be piped from the western terminal to Canada and the U.S.A. via Baffin Island /17/. At remote sites 60 Hz frequency is unnecessary. Inexpensive 2- and 4-pole generators would have AC output of varying frequency, voltage and amperage. Solid state rectifiers with controlled DC voltage output would power the electrolyzers, and hydrogen (oxygen) production would vary with electrical energy consumed. The average available head is 555m and estimated available power is 116,000 MW /27/. Similar, if lesser, remote sources of hydro power exist in Alaska, Central Africa and southeast Asia.

Alternate policies are needed to assure ourselves and our successors complete success in meeting future energy requirements. These include:

1. The main thrust of our efforts should be to encourage and develop alternate energy sources to slow depletion of irreplaceable fossil fuels, rather than the reverse.
2. We should continue to press for maximum funds and effort to develop fusion reactor plants if this be possible.
3. We should accept the fact that nuclear fission power plants are out-moded and concentrate on what to do with the cores when they are depleted to the point of no return.
4. We should limit our manufacture of synthetic fuels from coal to military needs rather than intensify the depletion of our coal reserves.
5. We should adopt the premise that fuel gas will continue to be distributed to homes and businesses for the indefinite future, irrespective of its makeup or source.
6. We should greatly intensify plans for using electrolytic hydrogen which can be fired in air at normal thermal efficiencies or can be recombined with electrolytic oxygen at higher efficiencies in fuel cells without fuel preparation sections, boilerless steam turbines and compressorless gas turbines.

Many alternate energy sources are variable. This particularly applies to solar energy which at best is a less than 50% proposition. This also applies to tidal power, river velocity power, wind velocity power and wave power. To operate such variable or remote sources on a firm basis requires storage of some or all of the electrical energy generated. Electrical energy can be converted into chemical energy on a one-to-one basis at low temperature by electrolytic dis-sociation of water. Both hydrogen and oxygen can be collected and stored. Hydrogen is a fuel. When recombined with oxygen, it burns to water vapor. Hydrogen has three times the specific heat content of petrofuels and four to five times that of the better grades of coal. It is naturally fluffy and must be used under high pressure, low temperature, or both, to equal natural gas heating value throughput in the same pipe. Also, it must be contaminated in the order of 1% to create an odor

for detecting leaks, luminosity to check burner performance, and prevent hydrogen embrittlement.

One of the driving reasons for our energy dilemma is the interlocking of price between various non-replenishable fossil and fissionable nuclear fuels. When OPEC oil prices rose from \$2 to \$30 per barrel during the 1970s, the price of other fuels also rose. Nuclear fuel rose by a factor of 7 in the form U_3O_8 and might have risen more in the absence of the need for expensive enrichment and cladding. After 1973 a major supplier of fuel elements cancelled its long-term contracts. If coal could be sold for the same cost per MBTU as oil, it would cost \$110 per ton delivered. Western USA coal presently costs \$50 per ton delivered, and might have risen more in the absence of the need for expensive equipment for handling, storing, pulverizing, soot blowing, ash collection and removal of objectionable flue gas ingredients. Present costs for thermal-electric plants are close to \$1250/KW (nuclear), \$750/KW (coal-fired) and \$350/KW (oil-fired). Oceanic hydro power and weightless solar energy collection should be pushed for the near term and fusion power for the long term, in addition to other smaller scale alternate energy sources listed earlier. At \$7.50/MBTU (present cost of fuel oil), an oil-fired thermal-electric plant is saddled with a fuel cost of 2.6¢/KW-HR which alternate energy plants using free sources of energy avoid altogether. This is quite an edge when costs of the necessary equipment are considered.

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THE ECONOMICS OF SOLAR, GEOTHERMAL AND CONVENTIONAL SPACE HEATING*

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EXTENDED ABSTRACT

In early 1979, conventional fuels dominated the U.S. space heating market. However, the competitive outlook for geothermal and solar heating changed dramatically during the past year due to sharp increases in conventional fuel prices. Fuel oil prices increased an average of 80%, and electricity and natural gas price increases averaged 30% nationwide in 1979. If conventional fuel prices continue to escalate at a rate above the general inflation rate, the number of locations at which the costs of solar or geothermal heating are below those of the competing conventional fuels will steadily increase.

The costs of residential heating using conventional, solar and geothermal energy were estimated for a number of locations throughout the United States. The GEOCITY [1] model was used to calculate the unit cost of geothermal heat. GEOCITY simulates the production, distribution, and waste disposal process for geothermal district heating systems. The unit cost generated from the model was then used to calculate levelized heating costs for five types of residences, which range from a single-family, suburban house to a multi-family, high-rise apartment. A model developed by Barley and Winn [2] was used to calculate the cost of solar heating. The Barley-Winn model is based on an empirical relationship between annual solar load factor and relative collector area. Again, the levelized cost of heating with a solar system utilizing conventional energy backup was calculated for the five types of residences. The levelized costs of heating with conventional fuels, oil, natural gas and electricity, were also calculated for the five residences.

Factors which influence the costs of heating with solar or geothermal energy were identified. Solar heating costs are very dependent on the total heat load per residential unit and on the available solar insolation. The total heat load, in turn, is dependent on the climate and the thermal performance of the building. The economics of geothermal district heating is dependent on a number of factors including: 1) climate, 2) population density, 3) resource temperature, 4) well depth, 5) well production rate, and 6) transmission distance.

Using calculated levelized heating costs, regions and applications were identified which show the most promise for near-term commercialization of

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geothermal and solar energy. Equally important, areas and applications were depicted which are not likely to be promising for solar or geothermal heating. Solar heating was found to be most economic for suburban space heating applications where heat loads per residence tend to be larger than those of urban dwellings. Geothermal district heating costs were found to be lower for high-density, urban heating applications.

Regions with the greatest potential for solar heating have high levels of insolation and high annual heating degree-days. As shown in Fig. 1, regions with these characteristics occur in central Nevada, Utah and Colorado. The next favorable areas are characterized by either high insolation or high annual heating degree-days. These regions of secondary potential are also shown in the figure.

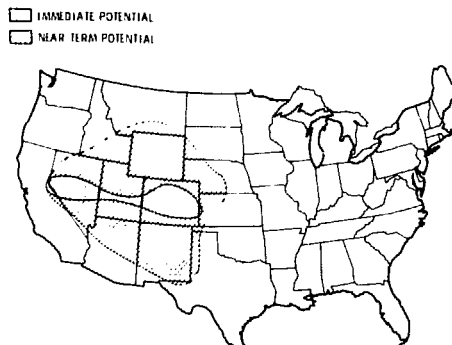


Fig. 1 Regions with the Most Promise for Commercialization of Solar Heating

Regions with the greatest potential for geothermal heating have high annual heating degree-days, high resource temperatures and short transmission distances. Urban district heating from the higher-temperature hydrothermal resources in the West currently appears to be an economic option for providing heat in at least six locations: Reno, Nevada; Idaho Falls, Boise and Twin Falls, Idaho; Helena, Montana; and Klamath Falls, Oregon. Under price decontrol of conventional fuels, urban district heating from other hydrothermal resources will probably become competitive throughout more of the West. These potentially attractive areas are shown in Fig. 2.

Conventional heating will continue to be most economic: 1) in the South (where annual heat demand is low), 2) in the Northeast and Midwest (where insolation levels are low and where known geothermal resources are not yet available), and 3) in the Pacific Northwest coastal region (where low-cost electricity is available).

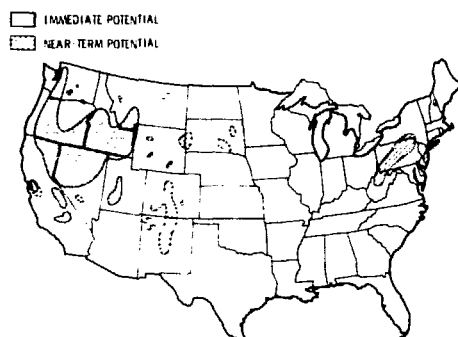


Fig. 2 Regions with the Most Promise for Commercialization of Geothermal Heating

In the West, where solar and geothermal heating show the most promise, natural gas dominates the space heating market. The trend in recent years in this area has been toward an increase in the use of electricity for home heating. Currently, natural gas and electricity capture almost equal shares of the new home heating market. Therefore, in the short run, geothermal and solar energy will be competing with natural gas and electricity for new heating markets, and primarily with natural gas in existing markets. With decontrol of prices, the market share of natural gas for new home heating can be expected to continue to decline. The choice of electricity for heating new homes can be expected to increase with a shift toward more efficient systems, such as heat pumps. Therefore, in the long term, it is expected that alternative energies will compete primarily with electricity. Geothermal and solar energy are not likely to be attractive for retrofitting on a large scale in the near term; however, retrofits will become increasingly attractive as conventional fuel prices continue to increase.

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POTENTIAL OF SOLAR FLAT PLATE COLLECTORS IN ISRAEL

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ABSTRACT

The use of thermal solar collectors is receiving increased attention, worldwide, as the price of petroleum continues to rise sharply. Part of the attention is directed towards the rate of installation of solar devices, consumer acceptance, product design and costs, rate of return calculations, and impact of government policies.

This paper will comment on these issues based on a recent study on the relatively extensive use of flat plate collectors for water heating in Israel.

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"OPERATION SUNPOWER: COMMERCIALIZING SOLAR ENERGY"

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America's dependence on foreign oil has necessitated the intervention of the federal government in the energy marketplace to speed up the timetable by which solar energy technologies are adopted on a widespread basis by hospitals, schools and other institutions.

It has long been the practice for federal dollars to be spent on the research and development of a host of products and processes. But never before has a major federal commitment been made to accelerate the utilization of products intended not solely for government use -- as has been the case with aerospace and military hardware -- but for use by a broad spectrum of society.

Toward this end, President Carter proposed, and Congress enacted, tax credits and other measures designed to provide financial incentives for would-be purchasers of solar energy systems. But simply to offer such incentives is only part of the solar commercialization effort. Equally, and critically, important is the broad-based marketing program now being carried out by four regionally-based and federally-funded solar energy centers, a program encompassing the providing of information and rendering of assistance to potential solar users.

In early 1979 the Northeast Solar Energy Center (NESEC) -- serving New York, New Jersey, Pennsylvania and the six New England states -- launched a massive marketing campaign, "Operation Sunpower." In concert with the solar industry and state energy offices in its region, the NESEC program sought to double in a single year -- from 5,000 to 10,000 -- the number of in-place solar installations. "Sunpower" sought to educate the public as to the benefits of solar and to the federal incentives available to solar adopters -- both the newly-enacted federal tax credits and \$400 grants available under a floundering HUD program intended to foster the use of solar water heaters.

"Sunpower" thus became the first test of the regional center concept and, indeed, of the viability of federal efforts to commercialize solar energy. It was a successful test, meeting its goal of 5,000 added solar installations through a wide variety of marketing and promotional activities. Workshops, speaking engagements, targeted mailings, and an intensive publicity drive -- reaching an estimated cumulative audience of 100 million people through free media coverage -- were among the tools used in the "Sunpower" effort.

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A key element in "Operation Sunpower," and indeed throughout regional solar energy center activities, is a partnership between the public and private sectors. Given the vast undertaking embodied in the attempt to wean the country of its oil dependency, neither the government nor industry, acting alone, can possibly achieve the goal established by the President for 20% solar contribution to the nation's energy supply by the year 2000. But together, given the proper resources and the commitment to that goal, government, the private sector and the general public can make a solid America a reality. "Operation Sunpower" has demonstrated that solar energy can be commercialized. And in doing so, it has provided valuable insights into the reindustrialization of the American economy.

IMPACT OF ALTERNATIVE TECHNOLOGIES ON ELECTRICITY PRICES
IN THE WESTERN UNITED STATES

by

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ABSTRACT

The nation's demand for electric energy will continue to grow for at least the next three decades. The rate of growth in the Western states is likely to be 2% to 4% per year, rather than the 7% to 9% growth rate experienced during the decade of the 1960's. However, whatever the growth rate, the decreasing availability of natural gas and oil, and limited hydropower resources, will mean that the nation must depend heavily on other energy sources for electric power generation. The Western states are particularly fortunate in having a wide variety of energy sources available. These energy sources will be utilized to various extents, and include nuclear, coal, geothermal and solar energy (including wind). This paper presents an economic assessment of electric power generation in various sub-regions of the Western half of the nation, assuming both high and low growth rates in electricity demand. The sub-regional "mix" of generating facilities that can be plausibly expected to be developed is delineated, alongwith the resulting electricity costs. The impacts of relatively more or less use of each energy resource, and of greater or smaller capital costs, will also be analyzed.

STEAM GENERATOR DEGRADATION AND NUCLEAR
POWER COSTS: A GENERIC PROBLEM

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EXTENDED ABSTRACT

INTRODUCTION

The progressive deterioration of steam generator tubes in over half of the United States' operating pressurized water reactors is a generic problem with far-reaching implications for nuclear power costs and safety. NRC and utility documents indicate that there is no existing technology for arresting steam generator corrosion and tube leaks. Thus, utilities have either begun or are planning total replacement of steam generators, a costly (\$500 million/plant) and highly radioactive task. This paper will review FP&L's steam generator repair proposal for Turkey Point and project national cost estimates for steam generator repairs.

HISTORY OF STEAM GENERATOR DEGRADATION

Steam generators provide heat transfer surfaces for the removal of heat from the reactor core, containment of radioactive products, and the production of non-radioactive steam for electrical generation. These components operate in a corrosive environment consisting of high temperature, high pressure, neutron radiation, dissimilar metals, and solids precipitated from various water chemistries during the production of steam.

Selection of water chemistry has been revised due to lack of effective data and adverse experiences with chosen water chemistries. Not all reactors have the same corrosion experiences. Turkey Point, Surry and Palisades have the most advanced deterioration. Lack of state-of-the-arts technology to arrest steam generator corrosion necessitates the removal of deteriorated surfaces (tube plugging) and the eventual repair or replacement of entire steam generator units. Industry and consumer costs are significant.

REPAIR ALTERNATIVES

Replacement has been chosen for the Surry and Turkey Point reactors. Other options, depending on plant circumstances, may be chemical cleaning, sleeving, or remote control tubing. Planning of steam generator replacement is subject to errors due to lack of experience, difficulties posed by the radioactive environment, inaccessibility of components, and rapidly escalating costs.

REPAIR COSTS

Major foreseeable costs include: engineering studies, steam generator components, labor, replacement fuel, worker exposure, decontamination, low-level waste disposal, cost overruns and inflation.

Significant additional costs have and may be incurred by utilities and manufacturers through litigation brought by consumers before the Nuclear Regulatory Commission, state public service commissions, and the federal courts.

ALTERNATIVES TO STEAM GENERATOR REPAIRS

The large capital requirements of steam generator repairs, the generic nature of the problem, the possibility of the recurrence of steam generator degradation after replacement require a comprehensive cost/benefit analysis of alternatives to steam generator repairs. This analysis would consider the options of derating impaired plants in favor of providing replacement power by fossil fuels and/or renewable sources of energy. State governments, public service commissions, and consumers may become involved in these policy decisions.

SUMMARY AND DISCUSSION

Two central problems are raised by steam generator degradation. Will steam generator repairs work? Who will pay for current and future repairs -- utilities, investors, manufacturers, consumers and/or the federal government? Large investments were made in nuclear power production during the 1950s and 1960s without full information on the myriad of unresolved problems associated with this technology.

In view of the multi-billion dollar investment that may be required to repair malfunctioning steam generators, now is the time to pause and re-evaluate nuclear power costs.

CUSTOMER COSTS OF INTERMITTENCY IN ELECTRICITY SUPPLY

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PRELIMINARY ABSTRACT

Consumers of electricity in the United States have long been the beneficiaries of highly reliable electric service. Electric utilities have accepted responsibility for providing this high reliability, and have expanded generating capacity to maintain reserves such that the probability of failure to meet expected demand has been very small. But over the past decade, rapidly escalating capital costs, uncertainty in future demand, and long lead times for new plants, have focused attention of utilities on the cost of maintaining high reliability levels.

Should electric service reliability levels decrease, consumers may become subject to more frequent interruptions in their supply of electricity. More frequent and longer electric outages would result in costs to consumers from lost wages, spoiled products, and decreased productivity. Recently, research has been directed at quantifying these potential consumer costs so that they might be balanced against utility system costs in planning future generating capacity. A number of utilities have conducted consumer surveys in initial attempts to estimate outage costs. Other studies have used aggregate economic measures such as gross national product per kilowatthour, and the "consumer surplus" approach in attempts to establish rough upper and lower bounds on outage costs. However, bounds based on these and other methods can differ by an order of magnitude.

Over the past year, the Institute for Energy Analysis has worked with the Tennessee Valley Authority in developing methods for calculating customer costs of electric outages in the TVA service region. These methods are based on specific electricity end uses or electric services provided in the Tennessee Valley. Estimates of costs of curtailed electric services within each customer class are made, accounting for the possible long-term response

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of consumers to mitigate outage costs. Customer- and class-specific costs are then aggregated over all customer classes to approximate a total outage cost for the region. The overall methodology supplements present procedures for capacity expansion planning, maintenance scheduling, and transmission system design.

THE EFFECTS OF REGULATION ON THE BEHAVIOR OF
PROFESSIONALLY-MANAGED UTILITIES

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Much of the literature on the effects of regulatory constraints has been concerned with the behavior of utilities characterized by profit maximization. Empirical search for the hypothesized innovation levels and the resulting Averch-Johnson effect has not generated conclusive support for the theory.

The mixed empirical results may be capable of supporting the view that regulatory constraints affect firms differently depending upon their structure. A particularly important characteristic of firms is the concern for profits on the part of managements. This concern is related to the extent that management owns the firms' residual claims. In the case of many utilities, professional management means divorce of ownership from the firm's decision-making.

In this paper the effects of regulatory constraints are studied on the basis of firm's behavior consistent with professional management. In a framework of a theoretical model the Averch-Johnson effect and propensity to innovate are a function of the extent to which ownership and management are divorced. Various aspects of utilities' behavior are studied in relation to the extent of professional management and exogenous forces such as the tightness of the regulatory constraint.

PERSPECTIVES ON STATE AND FEDERAL ROLES
IN THE
DEVELOPMENT OF ALTERNATIVE ENERGY SOURCES

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Abstract

Energy policy and energy policy studies have concentrated on activities mainly at the federal level. While this concentration is appropriate for some activities involving research and development, for a large number of other policies, it is the federal government which proposes, but the states which dispose. Since these levels of government respond to different pressures, it may be the case that the states are ahead of the federal government in responding to energy problems.

In addition to research, the federal government provides the states with funds to carry out various energy-related activities. Also, standards that states must implement are promulgated at the federal level. However, the federal role is not unlimited. The Congress can only reach as far as the Constitution permits. In particular, the ninth and tenth amendments as well as certain other clauses limit federal power.

Energy problems are usually solved at the state level. The states are responsible for writing buildings codes, controlling land-use and rights to land or water, utility regulation, etc. Many of these state-controlled areas include barriers to the development of alternative resources. As state responsibilities, it is the states which must solve them. Because the two levels of government often overlap, studying their activities will be useful in allocating roles, avoiding duplication of effort and spending public monies wisely.

The US is not unique in having sub-national territorial divisions with powers of their own. Canada provides an immediate example, with provincial policies often at odds with those of the central government. However the Canadian example is not unique. India, Brazil and West Germany all have regional governments. Comparing US forms with their foreign counterparts should provide useful lessons for our country, and allow presentation of conclusions and suggestions for future research.

THE ECONOMICS OF LONG-DISTANCE THERMAL ENERGY TRANSPORT
FOR DISTRICT HEATING APPLICATIONS

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EXTENDED ABSTRACT

There recently has been renewed interest in district heating in the United States because of its potential to conserve energy and its ability to displace oil and natural gas currently used for space and hot water heating by alternative energy sources. On a National basis, space and water heating account for almost 22 percent of the total energy demand of about 78 quads (quadrillion Btu) per year. Over 90 percent of this heat requirement is supplied by oil and natural gas.

Cities that install modern hot water district heating systems can use thermal energy from a variety of sources including coal and nuclear cogeneration power plants, industrial waste heat, refuse energy, geothermal reservoirs, and possibly solar energy. Existing electric-only power plants can be retrofitted economically to a cogeneration plant to provide useful thermal energy as well as electricity. When thermal energy is supplied by a cogeneration plant, the overall fuel utilization efficiency is as high as 85 percent; this is more than double the efficiency of an electric-only plant.

At one time, small cogeneration power plants in many U.S. cities provided steam for district heating and electricity. However, during the late 1940's, many of these plants were replaced by more economical larger units located a distance from cities. Energy transport by steam from these new plants was not feasible for technical reasons beyond a distance of about 5 miles. In addition, inexpensive oil and natural gas became readily available as an alternative to steam. Today, existing district heating systems, including those serving cities, Government institutions, and college campuses, satisfy only about one percent (0.16 quad) of the total demand for space and hot water heating in the United States. In addition to this small market penetration, there has been a steady decline in steam sales since 1972.

In contrast to the situation in the United States, many countries such as West Germany, Sweden, Denmark, and the U.S.S.R. have developed extensive district heating systems which are continuing to expand at a rapid pace. Many of these countries initiated large-scale development of district heating during the 1950's and 1960's using hot water as the energy transport medium. Pressurized hot water, typically at temperatures of around 250°F, is transported throughout the city in pipes up to one meter in diameter.

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The potential for accelerated district heating growth in the United States is great. Several studies have estimated the market in the year 2000 will be between 2 and 5 quads per year. However, the location of existing thermal energy sources often may be remote from urban areas where the heat is required. Siting new plants near metropolitan areas can be difficult because of environmental or other constraints. Therefore, long-distance thermal energy transport may be necessary.

This paper analyzes the economic viability of long-distance energy transport using hot water for U.S. conditions. The analysis is based on a number of cost estimates for installed hot water piping systems in both rural and urban areas. The total cost of delivered thermal energy, including operation and maintenance, is calculated as a function of transport distance, load factor, pipe diameter, and temperature difference between the supply and return water lines. A typical private utility fixed charge rate of 18 percent is assumed. Delivered energy transport costs from remote power plants are then compared to the cost of energy from an oil-fired boiler in individual buildings. Results of the analysis show that for oil costing \$30 per barrel, it is economically feasible, for reasonable load factors and temperature differences between supply and return lines, to transport thermal energy up to distances of about 60 miles.

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SESSION 3G

WIND ENERGY II

STABILITY OF LARGE HORIZONTAL-AXIS AXISYMMETRIC WIND TURBINES

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EXTENDED ABSTRACT

INTRODUCTION

Recent economic and performance analyses have shown that large power producing wind turbines can compete with fossil fuel and nuclear power plants. However, the economic viability and steady performance of a wind turbine are only meaningful if it demonstrates correspondingly acceptable dynamic performance. This paper examines the stability of large, horizontal-axis, axisymmetric, power producing wind turbines.

DYNAMIC MODELING

The dynamic model includes coupling of the rotor blades, tower and the power generating system. Both the rotor blades and tower are assumed to be flexible. Each blade is permitted two bending degrees of freedom, torsion and rigid body pitch control. Complex blade motion is modeled by considering the blades to be composed of an inboard series of massless, rigid links restrained by linear springs and dampers with a much larger massive blade attached to the outermost link. Blade bending is modeled as rotations about virtual hinges connecting the two outboard links. Only distributed torsion is allowed along the massive portion of the blade. Blade planform, mass distribution and aerodynamic section properties may vary along the span.

The hub, rotor shaft, and nacelle are rigid. However, the rotor speed is allowed to vary and may induce perturbation reactions within the power generating equipment located in the nacelle. The nacelle can yaw freely or in an elastically restrained manner. The tower can bend in two mutually perpendicular principal planes and is modeled by the first two bending modes of a cantilever beam in each plane.

EQUATIONS OF MOTION

The equations of motion of the wind turbine are linearized by considering small perturbations about an equilibrium state. The coefficients of these equations are, in general, harmonic about the rotor azimuth. For the axisymmetric wind turbines considered in this paper, a set of approximating

constant coefficient differential equations is obtained by describing each blade degree of freedom with multi-blade coordinates of the form,

$$q_k(t) = p_0(t) + p_1(t)\cos \psi_k + p_2(t)\sin \psi_k \quad (1)$$

where the individual blades are identified by the subscript k , and ψ is the rotor azimuth angle (1).

The result is a set of 18 linear, second order, constant coefficient differential equations of the form,

$$[M]\ddot{\bar{X}} + [C]\dot{\bar{X}} + [K]\bar{X} = \bar{0} \quad (2)$$

where $\bar{X}$ is an 18-dimensional column vector and M , C and K are the generalized mass, damping and stiffness matrices. These equations are derived in detail in reference (2).

The stability of the wind turbine is examined by first using state-space analysis to transform equation (2) into a 36-dimensional first order vector differential equation of the form,

$$[A]\dot{\bar{Y}} + [B]\bar{Y} = \bar{0} \quad (3)$$

Equation (3) is then transformed into a standard eigenvalue problem by substituting,

$$\bar{Y} = \bar{Y}_0 e^{\lambda t} \quad (4)$$

and then finding the eigenvalues, λ , which satisfy the equation,

$$|\lambda [I] - [A^{-1}B]| = 0 \quad (5)$$

The eigenvalues are, in general, complex. In order for the wind turbine to be stable, all real eigenvalues and the real parts of all complex conjugate pairs must be negative.

RESULTS AND CONCLUSIONS

All numerical results were determined for a 300 ft. diameter 3-bladed wind turbine with a rated output of 2 megawatts in a 25 mph wind measured at the hub. Each blade weighs 24,000 lb. and the rated tip speed ratio is 10. The blade lift coefficient is uniformly 1.0 at the rated wind speed. The tower is 225 ft. tall and has a reference weight of 330,000 lb. or about half of the total weight of the wind turbine. Some of the parameters

considered are wind speed, rotor speed, structural stiffness and damping and the effective stiffness and damping of the power generating system.

The results of this investigation indicate that the stability of large power producing wind turbines can be characterized by three conclusions:

1. Over a wide range of parameters wind turbines tend to be stable;
2. Their stability tends to be weak with the damping ratio of many modes being only a few percent or less of critical damping;
3. Unstable and weakly stable modes are dominated by motion of the turbine blades or tower in the plane of rotation.

As previously discussed, the wind turbine model has 18 degrees of freedom. This results in 18 modes of vibration. Of these 8 proved to be potentially unstable. Four modes were always stable but influences the stability of the other 8. Only the 6 modes dominated by blade pitch and torsion did not significantly influence the stability of any of the wind turbine configurations. The modes which, in general, showed the weakest stability (though not necessarily instability) were dominated by chordwise blade motion. These modes were stabilized most effectively by small amounts of blade structural damping, yaw damping and rotation of the principal blade bending axes. Additional unstable and weakly stable behavior can result from coupling between the tower and reactions within the power generating system. These modes can be stabilized by structural damping and stiffness in the tower and by properly tuning the effective stiffness and damping in the power generating system. In most cases of weakly stable or unstable behavior, the primary cause is from aerodynamic forces and the stability is the weakest at the rated wind speed.

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SYSTEMS DYNAMICS, CONTROL AND
ANALYSIS OF LARGE WIND TURBINES*

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Three areas of wind turbine systems dynamics and control are studied: steady state loading, stability and gust response. The use of blade pitch control is examined with a view towards reducing the steady fatigue loading from gravity, side winds, wind shear, and to attenuate gust loading.

The wind turbine rotor blades and tower are assumed to be flexible. Each blade is permitted two elastic bending degrees of freedom, one degree of freedom in torsion and controlled pitch as a rigid body. Complex blade motion is modelled by an inboard series of massless links restrained by linear springs and dampers, with a much larger massive blade attached to the outermost link. Bending along this portion of the blade is neglected, although distributed twisting is allowed. The rotor hub is mounted in a rigid nacelle which may yaw freely or in a controlled manner. The tower can bend in two principal directions and may twist. Tower bending may be anisotropic.

*Based on a Doctor of Philosophy Dissertation in Mechanical and Aerospace Engineering by M.S. Hirschbein with M.I. Young as advisor.

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The dynamic behavior of wind turbines is then described by a set of linearized perturbation equations of motion. These equations are, in general, harmonic about the rotor azimuth. Multi-blade coordinates are used to obtain an approximating set of constant coefficient differential equations. These equations are independent of the actual number of turbine blades, but apply only to axisymmetric rotors.

An integral part of this analysis is the development of an algorithmic approach to kinematics of wind turbine dynamics which allows numerically exact equations of motion to be derived by a digital computer. This permits a wide range of configurations to be considered.

Some of the parameters which are considered are as follows: wind speed, rotor speed, blade bending stiffness and structural damping, tower stiffness, effective rotor stiffness and damping, and the effective stiffness and damping of the yawing restraint.

PERFORMANCE TESTS OF PUSH-ME PULL-YOU BOATS AND VEHICLES

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EXTENDED ABSTRACT

INTRODUCTION

A push-me pull-you boat is a novel wind-driven water craft in which a windmill type air propeller is mechanically coupled to an underwater propeller [1]. Kinetic energy extracted from the wind by the air propeller is used by the water propeller to move the boat directly *against* the wind. In a similar manner, a wheeled vehicle can move against the wind by coupling the air propeller to a driving wheel [2]. Theoretical expressions for the performance of such craft have been reported previously [2,3]. In the present paper, performance tests of a wheeled vehicle having a 1.2 m diameter air propeller will be presented and compared with theoretical predictions. We expect that results from a boat using a 3 m diameter air propeller will also be available in time for the conference.

THEORY

Figure 1 is a sketch of a wheeled vehicle utilising three wheels in a tricycle configuration. Following reference 3, the upwind speed, u , of such a vehicle can be expressed as

$$u/W = \eta(1-a) / [1 - \eta(1-a) + C_D A_D / 4aA_1 (1-a)] \quad (1)$$

where W is the windspeed, a is the fractional decrease in windspeed at the propeller, A_1 is the area swept out by the propeller, A_D is the effective drag producing area of the vehicle frame and C_D is the corresponding drag coefficient. η is the overall efficiency of the system, i.e., the useful power supplied to the drive wheel divided by the rate at which kinetic energy is extracted from the airstream. The behaviour predicted by Eqn. (1) is shown in Fig. 2 where u/W is plotted versus a for several values of η , with $C_D A_D / A_1 = 0.02$. The upwind speed is very strongly dependent on η and a , exceeding 6 times the windspeed for $\eta = 1$ and $a \sim 0.07$ while it is less than the windspeed for $\eta < 0.6$ and any value of a . The optimum value of a for this device is much less than the optimum value for a stationary windmill ($a = 1/3$).

EXPERIMENT

Figure 3 shows performance data, u/W , for a wheeled vehicle using a 1.2 m diameter propeller. The triangles are from a two-bladed high speed propeller having a designed tip speed ratio of 5 and coupled to a 10 cm diameter driving wheel. The circles are from a four-bladed propeller having a tip speed ratio of 2.5 and coupled to a 28 cm driving wheel. The average performance is $u/W \approx 0.45$ for both propellers. Comparison with Fig. 2 suggests that our propellers are operating at $\eta \lesssim 0.5$. The performance is sensitive to the wheel diameter which must be matched to the propeller for optimum performance. For example, the four-bladed propeller stalls completely with a 38 cm wheel and performs poorly, $u/W = 0.17$, with a 10 cm wheel.

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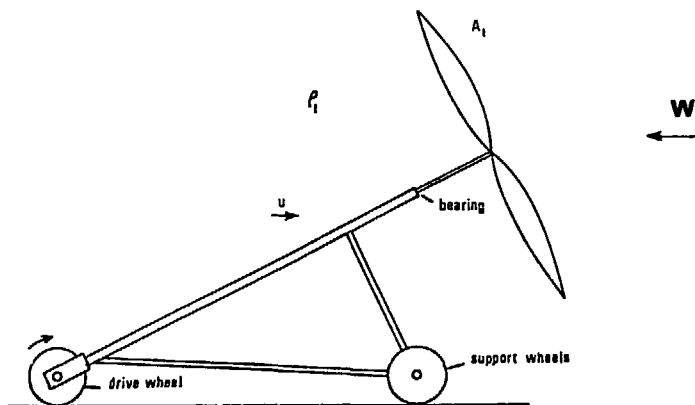


Figure 1. Sketch of a push-me pull-you wind vehicle.

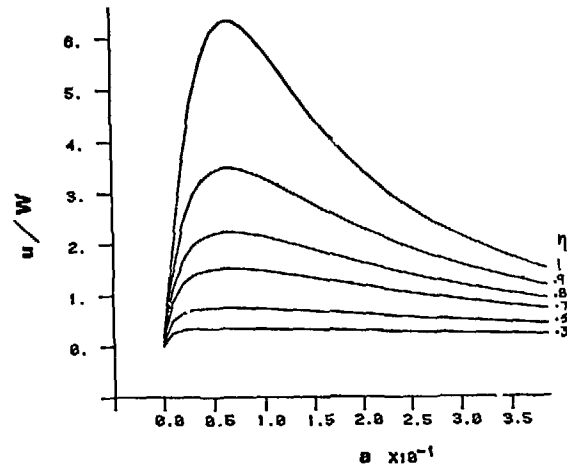


Figure 2. Predicted performance of a push-me pull-you wind vehicle.

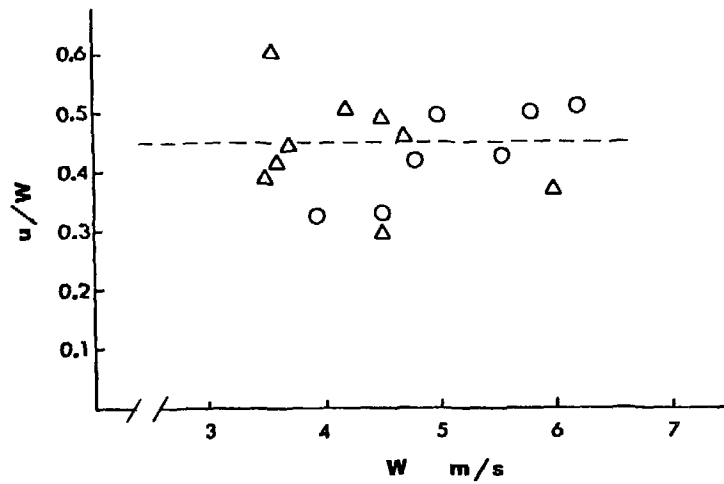


Figure 3. Experimental performance data for a push-me pull-you wind vehicle.

OPTIMUM DESIGN ASSESSMENT OF WIND POWER FOR HOUSEHOLD ELECTRICITY

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EXTENDED ABSTRACT

INTRODUCTION

This paper presents a theoretical and cost-effective design of a residential energy system. The system combines the use of a wind turbine with a thermal system forming resistance heating power; with a generator system producing alternate current (AC) electrical power and with a battery storage system retrieving direct current (DC) electrical power. This study developed a rational design assessment for a small range (10 to 200 kW) wind power generation. The primary objective is the development of a methodology suitably to be used by individual household electric utilities to assess prospects for wind power generation in their respective sites. A complete mathematical algorithms for evaluating and designing such system is presented. Simulated results will be demonstrated by a hand-held programmable calculator (TI-59 & PC-100C).

NEED

Recent uprising of fuel costs push us to evaluate an alternate residential energy resource so as to be independently supplied for utility power. Since wind is a free resource, according to an economical point of view, a need to develop an optimum wind turbine generator system for household electricity consumption is an attractive approach.

EVALUATION OF WIND TURBINE FOR RESIDENTIAL APPLICATIONS

The optimum total blade design of wind turbine is one that maximizes the product of the volumetric flow rate (small total blade area maintains a high volumetric flow rate of airstream) and the pressure drop across the turbine. Experimental evidence (R-1) indicated that two-bladed vertical-axis Darrieus rotor can be expected to reach a maximum power coefficient of about 0.35 at a blade-tip ratio of 6. Authoritative studies (R-2) highly recommended that Darrieus wind turbine was the most suitable choice for residential applications of small rated power output. Qualitatively, the elimination of yaw controls, ground level placement of mechanical equipment and low-cost blade fabrication techniques contributed directly into its low capital investment.

WIND POWER SYSTEM

Resistance Heating The wind turbine coupled with an integrated, slow-speed, direct-drive alternator which forms an ideal source of power for resistance heating. Since the heating needs no frequency control, producing heat in proportion to the available wind power, the system is an optimum design for hot water or warm-air heating. Domestic heating fuel savings are credited for penetration analyses.

Alternate Current Electricity Generating The wind turbine completed with a suitable generator system can provide 115/230 volt AC of 60 cycle output energy. Through a field modulated generator systems study, (R-3) it demonstrated that a variable-speed constant-frequency (VSCF) generating scheme appeared to be most attractive in the "small" (10-50 kW) and "100 kW scale" (50-250 kW) sizes. The system can be achieved optimally by assembling with a synchronous inverter (Gemini) which other than provides compatible power with the commercial power source; but to supplement the public power grid to the extent that available wind permits. Extra credits can be returned by the local power supply.

Direct Current Electricity Generating DC generation is practical only on a small scale at present, limited to about 10 to 20 kW (R-4). However, this is only true for the near-term batteries. Recent progress of emerging exotic advanced batteries (R-5,6,7,8) are to be optimized in this study. On the other hand, extra spaces for stacking battery modules and inherent drawbacks concerning safety aspects (R-9,10,11,12) are critical for optimum design. An attempt on deriving a mathematical model to determine the storage-device capacity, total throughout disposal of idle unused output to public power grid, energy deficit will be considered to improve the economic evaluations.

OPTIMIZATION

Methodology By carefully studying wind generation at suitable site (R-13) studies including effective system performance, impact and penetration analyses were simulated for optimum proposal. Additional goals included assessment of the interaction between wind generation and electrical energy storage development of preliminary recommendations.

Parameters The final output data are the capacity value, production value, energy cost, rated power output and annual energy, capital cost, penetration results, breakeven cost for optimization of the overall wind turbine generation power system. The input data are siting, median wind speed, metrological and time from the environmental system; rotor diameter, H/D & rpm from the wind turbine system; demand, output, excess, deficit and capacity from the storage system; performance efficiency from the generation and transmission system; cost and fuel escalations from the utility interface, initial capital investment and overheads systems.

CONCLUSIONS

Assessment of wind power for household electricity (10-200 kW) can be optimally achieved by designing a vertical-axis Darrieus-type wind turbine interconnecting with a variable-speed constant-frequency generating system in addition with a synchronous inverter and an advanced battery system for electrical energy storage. With this understanding, wind generation can responsibly be integrated into developing wind power module-plants to the public and for the public.

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THE WINDMILL OF DESIRADE'S WEATHER CENTER

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EXTENDED ABSTRACT :

SITUATION

The island of DESIRADE is one of the French West Indies Territories located very near from Guadeloupe. It is a little island of 27 Km² with 1600 inhabitants and was discovered by Colomb in 1493.

The weather center is at the end of the island on a promontory swept by the trade winds. From 10 years it uses a generator to produce its electricity but it was a troublesome solution : supplying of fuel by boat, frequent break down,... Because of the high wind (annual average of 15 - 20 Knots) the administration decided to test a windmill on this area.

CHOICE OF THE WINDMILL

The following positions of the weather center were to supply :

- lighting of the center (included the apartment of the director) :
 - 200 m² surface with 20 lights fittings
- transmitter - receiver BLU of 30 W
- typewriter and computer
- some receiving apparatus

Cooking and refrigerator with gaz

Choice of a windmill TURBO - ELECTRIC with nominal power 120 W/24 VDC which has a daily autonomy near of 2 Kwh/day and that should be more than enough to supply the needs

Setting up was made 12-20-1979

DESCRIPTION

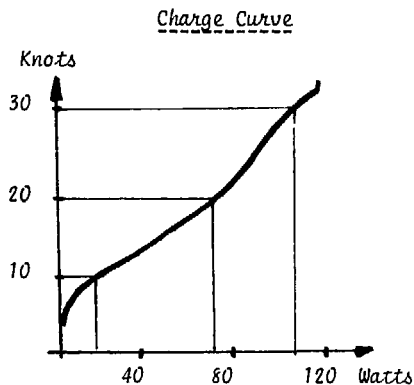
TURBO - ELECTRIC P = 120 W/24 VDC

is a three-bladed vertical turbine
with the following characteristics :

size : H = 1,70 m ; $\varnothing$ = 1,00 m

weight : 48 kg

charge curve : see right



The blades are in aluminium with protection of Rilsan and they are connected by stainless steel stabilisations bars eliminating all deformities. The windmill is setting up on the top of a 6 meters long mast $\varnothing$ 3" with double stay $\varnothing$ 6 mm and plastic protection. The turbine drives a two - phase alternator with permanent magnets which produces AC current conducted unto the weather center where it passes through an electronic regulation.

The function of the electronic regulator is triple :

- a) change AC current to DC current (24 VDC)
- b) limit the flow of current in order to avoid overloading the batteries
- c) dispose by thermic radiation any excess current produced after batteries are fully charged.

Storage is in 2 batteries of 200 Ah/12 VDC each connected in series. They are special long lived batteries with fiberglass separations and catalyst caps.

Finally we have direct lead :

- 1) 12 VDC for lights fittings (using of transistored light fitting 13 W/12 V)
- 2) 24 VDC for transmitter and receives

The use of a converter 24 VDC/220 V AC is in study.

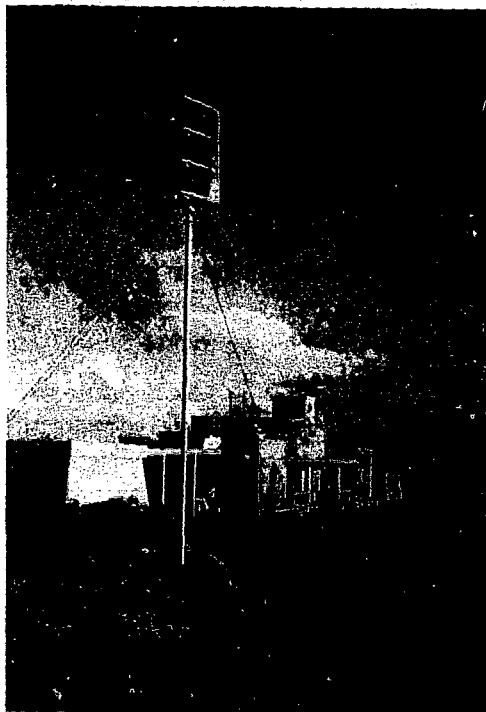
CONCLUSION

The silent working of TURBO - ELECTRIC is much appreciate by the occupiers of the weather center.

Functioning without any technical incident until yet.

Good running of the windmill and also of the blades' Rilsan protection (perhaps the main problem because of the erosive action of the nodules in the trade - winds)

In that case the transformation of wind energy into electricity is surely a better solution than the former one with a generator.



"WIND, PUMPS, AND DESALINATION"

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EXTENDED ABSTRACT.

Water poses a major problem in many areas of the world. Waterlevel is to be controlled, as in polders; in many places irrigation is essential to agriculture and worldwide the need for fresh, potable water increases. Moreover industry too experiences increasingly lack of water of acceptable quality. Interest is in pumping large quantities of water, in improving waterquality to acceptable limits, in many instances starting from seawater or brackish water of a suspect character, by lack of other sources.

This problem is the more severe, as it proves to be greatest in such areas as are deemed to belong to the developing countries and waterpumping and desalination demand energy. This commodity is in short supply and very expensive, as far as classical carriers are concerned. Would it be possible to harness present alternative sources to this end, so this would have a very positive effect. This applies to developed and developing areas equally well.

The sun as a source has been studied. But to use solar energy to the ends mentioned here this energy has to be converted to mechanical power to pump, and to either thermal power of sufficiently low cost or cheap high pressure for desalination by means of evaporation or reverse osmosis. Although the sun provides between 832 kWh/m^2 , a and 2.540 kWh/m^2 , a this is converted into pumpingpower with an efficiency of about 7,5% only, be it via the thermal route or via the use of photovoltaic cells. The investment in solar pumpingplant per unit collecting area is considerably in excess of a sum of 1.250,-- dollars/ m^2 . Even at an annuity of 10% only, the water pumped costs between 66 dollarscents and about 2 dollars per kWh! Even the advantage of little need for long-term storage does not help.

Desalination on the basis of solar energy offers a comparable bleak prospect yet. Reverse osmosis needs high pressures, of the order of 6 MP and more. So, although the energyconsumption is not very high, of the order of 15 kWh/m^3 , these are expensive kilowatts in the form of electric current. Its costs are indicated above. Likewise it proves, that evaporative processes like the simple solar still or solar-energized multiple flash evaporation lead to costs in excess of 20 dollars per cubic meter, costs of energy only, but accounting for the solar installation.

It proves, that in such areas, where wind is available, matters are better.

Practice has shown, that for wind-speeds in excess of 3 m/sec. up to velocities of about 20 m/sec wind-energy can be put to proper use. As gained from the well-known power-formula for wind-turbines:

$$N_p = C_p \cdot 1/2 \cdot \rho \cdot V^3 \cdot \text{Surface-area} \quad (1)$$

increased wind-speed has a very positive effect on power available. For areas, where average wind-speed amounts to 3,6 m/sec. already considerably more than 255 kWh/m², are available depending on the actual velocity-spectrum, whereas for an average annual velocity of 5,6 m/sec. this amount is 961 kWh/m², a. However, that is, based on the linear average. Taking the actual spectrum, this amount is over 1.516 kWh/m², a. For practical values of C_p , about 0.36, and at the optimal value for the ratio Tip-speed/wind-speed, λ , resulting in that C_p value, over 30% can be turned into useful mechanical power or heat. A prerequisite is, however, that C_p is kept at optimum value, so λ is kept at optimum value, throughout the working range. But that being warranted, the machine produces day and night, summer and winter, with little long-term deviations.

But use of the full power available at low costs is only possible, when turbine and machine driven are ideally matched and, at the same time, are cheap and very reliable and long-lived. Torque and power characteristics have to be matched in full over the whole operating range, without control-mechanism, as this increases costs and decreases reliability. So the machine driven has to have a third power of speed characteristic. The machine driven has to have the same torque-characteristics complyable with stable operation when WECS-driven. Introducing λ these machines show T or torque:

$$T = C_p / \lambda \cdot 1/2 \cdot \rho \cdot V^2 \cdot \text{Surface-area} \cdot \text{Turbine-radius} \quad (2)$$

As regards pumps only centrifugal pumps, conical pumps or screw pumps comply. Moreover, only low-head, high-volume, high-diameter pumps can easily be accommodated, as otherwise the gearratio between turbine and pump reaches values over, say, 30, as typical turbine-speed will be of the order of 100 rev/min. Piston pumps or other volumetric appliances show characteristics so different from wind turbines, that either sophisticated control or considerable loss of potential energy-harvest follow. As we strive for cheap power, this is not acceptable. Calculations show, that for the turbines under consideration, using direct coupling between turbine and pump, with fixed gearratio, the highest heads that can be attained by simple means amount to 20 m water. That is insufficient for either deep-well pumping or reverse osmosis.

The systems considered have to be proven, simple and cheap. As a consequence, size should stay within actual industrial practice, as materials for the turbine should. So stay within the practice of industrial fan manufacturers. That limits sizes of turbines to about 20 m diameter maximum, with as material reinforced plastic, e.i. glass-reinforced epoxy. That feature limits turbine power to about 250 kW continuous. In gusts this power might double for a short while, but jolts, jars, etc. will never occur. So automotive parts for gears, brakes etc. are ideally suited for the drive-train. These parts are reliable, cheap, and made to operate under all climatic conditions.

For simplicity's sake the turbine has to be of fixed pitch, with overspeed brake only. No electricity as intermediate, as this would also spoil the match.

Which turbine to choose, horizontal or vertical shaft? Definitely not more than two blades, for cost reasons. Special starting devices increase costs. C_p -values of vertical axis machines are lower than for horizontal-axis ones. Additionally, due to the very narrow shape of the power-speed ratio characteristics over vertical axis machines, in their case maximum torque and maximum power coincide, resulting in instable operation. For horizontal axis machines lower speed results in higher torque and vice-versa, giving stable operation. For the same swept area, the length of Darrieus-blades is longer than for a horizontal-axis machine. So the choice is for a horizontal axis machine with two fixed blades, coupled through fixed gears to the screw pump to be driven. Turbine diameter is 20 m max. As an extra-feature, through proper choice of profile and pitch C_p is virtually constant in a λ -range from 4 to 11! This feature automatically optimizes power use.

Total costs of such pumping plant prove to amount to about 300 dollars per m^2 turbine-area, all costs included, resulting in the pump-kWh in the water pumped costing 4 to 6 dollarscents only. The specific value of the system is, that it is self-optimizing.

For the production of heated liquid, as for example needed to feed multiple flash evaporation plant, temperatures of about 120°C are ideal. To generate such temperatures, the liquid under consideration can to advantage be fed through the well-known water brake. When operated under full-flow conditions, these machines by their very nature have the same power- and torque characteristics as screw pumps, rendering them ideally suited to be powered by the wind-turbine described before. These waterbrakes generate their own transport pressure in the liquid heated by their action, so that a simple thermostat valve keeps the temperature of the liquid leaving the brake a constant. The heated liquid is then fed to multistage or single compressor flash evaporation unit in the usual way. Prime pump and compressor are also directly driven by the turbine. As a consequence operation is entirely stable and automatically optimizes for maximum use of the energy available in the wind. Accounting for the costs of wind turbine, pumps and evaporation unit, it seems that such plant would produce fresh water of less than 50 ppm salinity at a cost of less than 3 dollars per m^3 . This is not as cheap as is possible on the basis of zero-cost energy. But in comparison to the solar-driven systems this looks very rewarding. Moreover, this is indigenous energy in the most literal sense.

It may well be expected that the turbine-pump-waterbrake concept developed here will have increasing practical application.

AVAILABILITY OF WIND ENERGY IN SAUDI ARABIA AND ITS APPLICATIONS

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INTRODUCTION

Wind energy application in the production of electricity in Saudi Arabia has got great potentiality. However, as is the case in any other places, the wind energy is intermittent. One important advantage for the Eastern Province of Saudi Arabia is this, the wind is from one direction for most of the time of the year. At the present cost of fossil fuel in Saudi Arabia, the economics of aerogenerator is not likely to be attractive. But keeping in mind the future, it is worthwhile to examine the potentiality of this natural source of energy. In this paper, long term meteorological data for several weather stations in Saudi Arabia have been analysed to obtain wind pattern and characteristics. Availability of energy is estimated on the basis of fundamental fluid flow analysis and a procedure is presented for that purpose.

Wind Energy Relation

The amount of kinetic energy contained in m Kg mass of air is given by:

$$KE = \frac{1}{2} m V^2$$

Where KE = Kinetic energy J
 m = mass of air kg
 and V = velocity of air m/s.

The mass of air in a flowing fluid of velocity V per unit cross-sectional area of flow is given by ρV Kg where ρ is the density of air and is equal to 1.22 Kg/m^3 . Thus, if the wind is available for T hours, then the amount of energy is given by:

$$\begin{aligned} E &= 3600 \left(\frac{1}{2} \rho V^3 T \right) J \\ &= 3.6 \times 10^{-6} \left(\frac{1}{2} \rho V^3 T \right) GJ \end{aligned}$$

Wind Energy Distribution

Normalised cumulative distribution for fourteen observing sites in Saudi Arabia has been made. The normalisation is done with respect to V_{50} where V_{50} is the speed exceeded 50 per cent of the time. Normalised wind speed contour map for Saudi Arabia has been drawn and a contour map for the annual wind energy has been developed.

Application to Houses

The application of the wind energy in the environmental control of houses has been discussed.

EVALUATION OF PRODUCTION COSTS AND CAPACITY CREDITS
OF A WIND ELECTRIC CONVERSION SYSTEM
SUPPLYING AND ELECTRIC UTILITY

by

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ABSTRACT

Since the 1973 oil embargo and the ensuing increase in fossil fuel prices, many electric utilities are paying more serious attention to unconventional but renewable energy sources. Most of the applications for the electric utilities' generation system are categorized as intermittent sources of energy. An intermittent source is one in which its power output may fluctuate from zero to maximum within a small time interval and upon which the utility dispatcher has very little control.

The reliability and economic questions posed regarding the integration and impact of an intermittent energy source, such as the wind, are similar to those which utilities must answer in evaluating their resource plans. A large part of the total cost of a wind electric conversion system, or WECS, is the cost of an energy storage device to assure a power supply when there is no wind. The cost of installing WECS can be reduced considerably by eliminating the storage device and operating the wind generator on a non-demand basis, that is, the electricity generated is dumped directly into the electric power grid. WECS are probably the closest to economic feasibility insofar as the production of electric power is concerned [1,2].

The study as reported in this paper is limited to WECS without storage capacity. Probabilistic simulation [3] is used to determine the value of WECS and to accurately assess its impact on system reliability, capacity reserve margin, increase in load carrying capability as well as production costing.

Because of the variability of the wind, the WECS power output consists of many capacity states. The procedure that is followed is to convolve the hourly probability distribution of unavailable capacity of the WECS into the hourly load distribution. Additionally, because of mechanical equipment failure of the WECS, the probability of the different wind capacity states are modified to reflect the effect of wind and forced outage due to mechanical failure.

The convolution procedure over the 24 daily distributions is accomplished very efficiently by the method of moments [4]. This method is based in obtaining the statistical moments and cumulants [5] of the different probability distributions. Convolution or deconvolution is simulated by the addition or subtraction of the appropriate cumulants. From the cumulants the Gram-Charlier expansion [6] may be used to evaluate LOLP, reserve margins, capacity credits and expected energy generation.

The method is applied to the IEEE Reliability Test system [7] and the impact of different penetrations of WECS is assessed.

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CLEAN ENERGY DEVELOPMENT IN THE CARIBBEAN AS A MODEL
FOR TROPICAL DEVELOPING NATIONS

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EXTENDED ABSTRACT

Energy production and extraction technologies have chiefly been invented in the temperate zone and have been secondarily transferred to the tropics, where most developing nations occur, without heed to environmental effects. The technology itself may function similarly in the tropics, but the environmental constraints differ widely: the tropical ecosystem, more fragile, pollution effects, greater, recovery times after impact or accidents, longer.

Energy (production and extraction) will be the most polluting global activity of the future (Russell Peterson, formerly of U.S. Council on Environmental Quality and presently head of U.S. Audubon). The U.S.A. policy now requires energy technology to transmit the environmentally least-damaging technology under its National Environmental Protection Act of 1969; however, do actions comply with policy? NEPA also requires new "alternate" technologies to be designed environmentally least-damaging. In some new technologies, such as DOE's OTEC program this is being seriously studied for tropical nations; in other new alternative technologies, the engineers and managers are not yet aware that "tropics" present a different set of environmental problems. In general, orders of magnitude more money and time have been spent ascertaining environmental effects of temperate (and sub-Arctic, especially Alaska) energy effects on environment by developed nations (e.g. U.S.A.). Research on tropical environmental energy effects has been grossly underfunded relative to their long-term global effects (Global 2000).

In a Vienna (October 1979) U.N. Conference on Research and Development, the developing nations (LCDs) demanded a greater amount of technology to be transferred to them. A highly "appropriate" and fairly inexpensive technology to be transferred would be environmentally least-damaging techniques along with energy technologies. This preplanning is the cheapest and most efficient method of assuring a sustainable world resource in the future (Global 2000 and World Conservation Strategy). The above transfer is not likely to happen by itself.

The "good" news to developing nations is that they do not have to repeat the expensive resource mistakes of the industrialized nations. Simple, low-cost solutions to mitigation of resource damage (with respect to energy extraction and production) are available. Those that are not yet available could be so in a short time at low cost. Preplanning for environmental problems is the cheapest long-term solution. Other good news: the alternative energy sources and production generally are far less polluting than conventional ones. Imaginative new schemes for the use of wastes also reduce pollution.

The Caribbean is an excellent model for "appropriate environmental energy transfer" for LCDs. 1) More is known about energy effects (Thorhaug 1980) than most other tropical seas due to U.S. DOE environmental research programs in south Florida and Puerto Rico, and certain Caribbean nations' long-term resource commitment (Netherlands Antilles, Costa Rica, Mexico and Venezuela). 2) The region is fairly homogeneous in ecological zones. 3) A rapid energy development is taking place, including a great variety of "alternate energy" experimentation (UNEP 1979). 4) It is a multilingual (4) and multi-cultural area. 5) The nations are beginning to see themselves related to a single common resource in which energy pollutants may poison all nations.

A recent meeting of the Caribbean Workshop on Environment and Energy at Florida International University began an intensification of the focus of the problems of the Caribbean. A previous UNEP study had documented energy plans and alternate energy in the Caribbean, but had paid little attention to the specific Caribbean environmental problems. This group considered the total Caribbean environmental problem with respect to energy including legal, political, sociological and economic factors outlined in the near future. Priorities included information needs and processes by which environmental considerations could enter energy decision-making for production, transmission, and extraction. A fuller report of these will be given. The process by which environmental assessments by TROPICAL experts can be successfully integrated into energy decisions is by 1) international loan institutions requiring or strongly recommending excellent assessments; 2) engineering awareness of total effects of energy projects; 3) governmental environmental consciousness-raising with regard to natural resource value and potential inadvertent and unnecessary resource losses during energy development; 4) media participation.

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Until nations obtain their own environmental assessment capabilities, having energy resource impact assessment by TROPICAL energy-environmentalists is essential to rational resource preservation for future generations. In the interim, advanced training programs for energy planners, developers, and engineers as well as resource managers are necessary in and for LCDs.

SOLAR ENERGY IN THE U.K: A MARKET PENETRATION MODEL.

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EXTENDED ABSTRACT

This paper describes progress towards the development of a model of the market for solar water heating in the U.K. A number of possible approaches are reviewed including the MITRE Corporation's SPURR methodology. The problems of applying such a model to the British market are examined. The aim is to develop a model suitable for the analysis of policy and for assessing the implications of government and marketing actions, in particular, the effect of the timing of such impacts on the developing structure of the solar energy market.

While the popular approaches using market substitution and market diffusion models provide a powerful insight into the future size of the market under a range of costs and consumer preferences, these methods are inevitably limited by the form and complexity of the data they are able to accept. Two examples are given below to illustrate the significance of these issues of information and structure, in the context of the uncertain early years of market growth.

Firstly, the decision sequences or packages of options facing the consumer in both the new housing market and the retrofit energy conservation market are seen as having considerable importance. The usual analysis of market penetration by considering competition for market share between different fuel sources or heating systems may be inadequate if the product is viewed as competing with investments both in other energy conservation measures and in terms of investment in the value of the property itself. Thus the complexity of the housing market including the cost, availability and restrictions on mortgage and credit, as well as the consumers' perception of these factors, needs to be considered.

A second area of significance lies in the need to differentiate between the utility from a solar energy installation derived by different groups of consumers. The decision to buy will depend on the value attached to solar energy by the prospective consumer. Value may be derived not only from direct cash savings, or the security of future savings in a period of inflation, but also from certain unique properties of the solar energy product such as the use of renewable energy resources as opposed to the depletion of fossil fuel reserves, the provision of a measure of energy independence, or simply from its newness. The significance and value of these properties will vary from individual to individual, and will also vary over time as the market develops and different consumer groups come to dominate the market. Additionally, different consumer groups

are influenced differently by the actions and views of authorities and information media. Lower income groups are also less likely to take or be offered credit for a relatively high risk innovative product. They will require greater confidence in its performance, and stronger guarantees, but they will save more as a percentage of income by energy conservation measures than higher income groups. Thus, any market penetration model to be used for policy analysis must incorporate some description of the structure of the consumer market, and the likely changes in that structure as information spreads, restrictions ease, cost-effectiveness is improved and confidence increases.

The early stages of marketing any innovation are characterised by firstly, a diverse collection of information ranging through vague feeling to strongly held, albeit subjective belief to hard ratio-scale data which may or may not be credible. In other words, data may be incompatible on three dimensions, of measurement scale, degree of confidence and degree of objectivity. Methodological responses vary from the use of only the objective, ratio-scale data available in conjunction with wide-ranging sensitivity tests, to movement to a more macro-scale to dampen out local irregularities, or to a more micro-scale to collect more detailed behavioural data on motivation or intention to buy. All of these responses provide a different view to enrich our insight into the system. However, in this study it was felt that a model framework was needed which would firstly, extract the maximum intelligence from all sources of information, and would be robust enough to accept upgraded data as it became available, and secondly, would emphasise the role of the complex relationships between factors; in other words, an emphasis on structure.

The approach adopted is based on Fred Roberts [1] structural modelling method based on signed digraphs. Structural modelling refers to a group of techniques recently developed as methods for analysing and forecasting complex social phenomena. The approach is particularly relevant to the study of innovative technological solutions to social and political issues, in that it examines the structure of social, political and economic systems, and the long and short term repercussions on the system, of interventions, whether they be political policies, market innovations or natural catastrophes.

In general, Robert's model is formulated by following three steps: first, the variables relevant to the issue being considered are identified; then, any significant interactions between pairs of variables are defined in terms of a positive or negative effect exerted by one variable on another; finally, where possible some form of weight is specified reflecting the relative importance of these interactions. In some cases, functional relationships between pairs of variables may also be available.

The model is then capable of analysis in a number of ways. The structure itself, and the identification of negative and positive feedback cycles

give indications of the stability of the system. The effect of a given policy may be traced where it can be interpreted as the strengthening, weakening, reversal or deletion of a link between variables. For example, the introduction of generous solar zoning into planning controls may have the effect of changing the sign on the link between solar sales and planning control.

The next stage in analysis introduces a specific rule to trace the effect of changes in the value of certain variables on the other variables. In Robert's terminology, a 'pulse' is assumed to be introduced through one or more variables and the effect is traced as a pulse process moving through the system changing the value of the variables. This pulse may represent for example, the effect of some technical improvement which reduces the cost of the solar installation, but equally, the effect of media reporting of solar installation failures might be interpreted as a pulse introduced through the 'public-attitude' variable.

The application described in this paper uses a combination of published statistics, questionnaire results and expert panel judgements to formulate the model and derive the data. The selection of variables is primarily achieved through the use of a relevance tree analysis to provide a comprehensive and categorised list. Information on relationships between variables is mainly subjective and was derived from the estimates of expert panels, who also provided subjective data on the values of variables and pulses, where this data was not already available from some credible objective source. For example, government data on new housing starts and population growth were used, but subjective expert estimates of future collector panel costs were sought.

It was found that the analysis of market stability, and stabilizing strategies were of considerable importance when related to the forecasts of market growth. In addition the role of the model in focussing attention on critical areas for data upgrading and model and policy development was shown to be significant.

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Abstract

AN APPROACH TO ENERGY POLICY PLANNING AND ASSESSMENT

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Failure to include non-quantifiable social and institutional factors affecting energy policy decisions is common to most energy policy planning models. To compensate for this deficiency an approach has been developed which should pinpoint these factors. A specific energy policy action often impacts upon some non-energy policy; stockholder, or institution generating a response that nullifies or modifies the proposed energy policy. The methodology presented is an attempt to systematically identify these negative responses and their origins in advance. Since there are positive impacts that can offset the negative ones, the energy policy maker is assisted in choosing a better balanced package. Although the representation of those interactions can only be qualitative, some possible evaluation methods using ordinal Ranking schemes or non-parametric statistics may be applicable. The major unresolved difficulty is in identifying a technique for trading off the advantages of energy improving activities against their associated societal and institutional disadvantages.

CHARACTERISTICS AND OPTIMUM END USES OF ALTERNATIVE ENERGIES

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EXTENDED ABSTRACT

Historical growth patterns of U.S. energy consumption were interrupted in the mid-1970's. For the prior twenty years, total consumption increase had been approximately 3 percent per year. Consumption for electricity had increased by 5 percent per year, achieving a 25 percent share of the total. A common estimate of things to come projects both rates of increase cut in half between now and the turn of the century.^[1] The double influences of conservation and inflation have thus made planning for electric capacity challenging in prudently scheduling new construction and problematic in providing adequate revenue.

Of the approximately 40 quads of annual energy increase between now and the year 2000, nearly 25 quads will be in the form of electricity (source energy consumption computed at approximately 10,000 Btu/kwh). Currently-planned addition of coal-fired and nuclear generating stations each account for approximately one-third of this increase in consumption.^[2] Thus 5 - 10 quads of total electric energy market could be divided between cogeneration, solid waste conversion, new hydro-electric facilities and various alternative energies.

In particular, five alternative energy options (wind, wood, solar, geothermal and coal conversion) are close to technical and economic feasibility. Wind energy is most available in the middle of the day and least available in the summer, synchronous with utility peaks in northern latitudes. Unfortunately, wind energy is intermittent and to achieve reliable capacity, storage is required. Hydro-electric capacity can be used to "firm" the energy available in the winds, by deferring the discharge of water when the wind is meeting requirements. Wood must be combusted to release stored energy, however, it is sulfur-free. Use of forestry residues in central stations can also lessen environmental problems. Solar energy can be concentrated and utilized in a conventional electric power plant or photovoltaic cells can directly convert sunlight. The sun can be relied upon particularly in southern latitude, a larger percentage of the time to meet peak electric loads than wind. If storage is desirable, thermal storage at a solar-thermal plant is less costly than battery storage at a photovoltaic plant.^[3] Geothermal energy must be discovered in much the same fashion as oil and is also expected to suffer depletion over time. The mining of coal to supply new conventional central stations, converted oil and gas-fired facilities and higher load factors at existing central stations will account for approximately a doubling of current coal production. Any additional increase may be used for synthetic fuels. In those instances where a coal seam is uneconomic to mine and where coal quality is not readily controlled to meet environmental restrictions, gasification processes will be employed. For central station use, only low and

medium Btu gas is necessary.^[5]

A review has been made of these five alternatives on the basis of four characteristics (schedule, cost, resource, environment) related to their feasibility. Each alternative was assumed to be sited at an attractive resource and sized to take advantage of economies of scale. Looking at the schedule criterion in terms of status of technology, environmental permit and construction requirements; the solar alternative is least attractive. Reviewing cost in terms of investment, fuel and conversion efficiency, and capacity factor; the solar alternative is again least attractive. The resource criterion was broken down into potential and projected utilization (on the basis of proponents estimates).^[6,7,8,9] Comparing the two values shows that neither solar nor coal conversion are attractive options. The environmental characteristics of the alternatives were evaluated as either better or worse than a selected baseline. These included water and land use, impacts due to operation and constraints on siting. For various reasons, no particular alternative stands out.

Space and water heating requirements in the commercial and industrial sectors are projected to account for approximately one-half the increase in annual energy consumption. For these end uses there is no justification for losing efficiency by running a working fluid through a power cycle. These needs should be served at the load by natural and synthetic gas or solar energy.

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A TECHNIQUE FOR THE EVALUATION AND COMPARISON OF
ALTERNATIVE ENERGY TECHNOLOGIES UNDER UNCERTAINTY

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EXTENDED ABSTRACT

Significant uncertainties beset virtually all of the alternative energy technologies being considered to replace our conventional energy sources. These uncertainties are both technical and economic in nature, including uncertainties over: R&D cost; production cost; technical performance (including the possibility of failure, in some cases); schedule; market size and penetration; the cost of competing sources; environmental, regulatory, and political requirements.

Standard economic evaluation techniques which produce a point estimate of economic performance are inadequate and unreliable for assessing alternative energy technologies. Results from such evaluations are largely determined by the assumptions made in the face of substantial uncertainty by the individual(s) conducting the analyses. Such results are not comparable to evaluations of other technologies for the purpose of developing an economically sound R&D program for the development of alternative energy sources. Furthermore, most of the information which would be useful for decision-making has been eliminated in the construction of deterministic (point) estimates. Individual project managers or proponents of new technologies need to be able to identify critical uncertainties to efficiently focus their R&D efforts. Energy planners must certainly consider uncertainty (risk) in selecting among competing short- and long-term options. Even sensitivity analyses fail to reflect properly the effects of uncertainty in that they do not capture interacting sources of uncertainty nor do they reflect the probability of occurrence of the variations being considered.

A technique is presented here for evaluating alternative energy programs (from R&D through commercial implementation) explicitly accounting for uncertainty. Results using this approach are produced in the form of probability distributions of any technical or economic parameter desired (such as user charge in mills/kWh). The approach is decision analytic in nature and requires the creation of engineering and cost models of the proposed system and a model of the economic value of the system as a function of its technical performance. In addition, R&D programs are represented as "decision trees" identifying program phases, decision points and the range of possible outcomes at each decision point. This approach reflects the true range of options available to program managers to modify (or even terminate)

energy research programs based on the results obtained from R&D activities. Economic evaluation techniques which fail to capture this aspect of R&D programs systematically underestimate the economic value of developing alternative energy sources.

Input data for the models are systematically collected in the form of probability distributions from experts for each individual technical or economic parameter. The distributions are generated by having each expert specify minimum, maximum and most likely values for a given parameter and select a shape for the distribution (from a list of alternatives) which reflects his or her confidence in the estimate. Sharply peaked distributions, for instance, reflect a more advanced state-of-knowledge, whereas a flatter distribution indicates that the expert has less confidence in his or her estimate of the most likely value of the parameter. Uniform procedures are employed in collecting these data to insure the consistency of data from different experts on different parameters. Where irreconcilable differences exist between experts on the same parameter the system models should be exercised for each estimate of the disputed parameter to see if a significant discrepancy results in estimated system cost or performance. If so, then immediate further analysis or experimentation may be desirable to resolve the issue. The approach to data collection described here differs from other attempts to quantify subjective technical judgement (such as the Delphi technique) in that it focuses expert attention of very specific questions and collects more detailed information from each expert.

Appropriate simulation techniques are applied to the models and data described above to calculate an expected value for a program from R&D through commercial implementation. These techniques are Monte Carlo based and involve either forward simulation with an arbitrary decision rule or backward induction to calculate an economically optimal path. Forward simulation techniques are useful for dealing with large or complex decision trees, but care must be taken that the results of the analysis are not overly sensitive to the decision rule employed. Backward induction techniques are more desirable in that they simulate economically optimal behavior; however, the computational requirements become excessive when one tries to apply such techniques to large problems. Efforts are currently under way to develop more efficient algorithms. It is frequently possible to optimize individual projects using backward induction and then use forward simulation to evaluate combinations of projects.

The standard deviation of the estimate of the expected value of a program serves as an explicit measure of program risk. Individual projects and programs may then be compared on the basis of both expected value and risk. Economically "efficient" projects or programs, that is, those offering the highest value for a given level of risk may be identified. Using this information, combinations (i.e., portfolios) of low-, medium-, and/or high-risk programs may then be selected based upon the decision-makers attitudes toward risk. Portfolio selection techniques have long existed to aid in selecting projects on the basis of expected value and risk, if the projects

may be viewed as independent. More recently efforts have been directed at reflecting the different types of interdependencies which occur in R&D programs. Examples of such interdependencies include: mutual exclusivity (e.g., two or more projects requiring a facility which can only be used by one project at a time); contingency (e.g., Project A must be completed before Project D is initiated); technical interdependence (e.g., the outcome of one project significantly affects the outcome of another); effect interdependence (e.g., the outputs of two or more projects programs combine - either positively or negatively - in a non-additive way with respect to some measure of program value). Which of these types of interaction should be included in any particular evaluation depends on the nature of the technologies involved and the questions the analyst wishes to answer.

The approach outlined here also readily identifies major cost and risk drivers for the system under study by evaluating the effect on total system cost and risk of the uncertainty that exists on individual technical and economic parameters. R&D programs may then be designed to efficiently control risk in pursuing alternative energy concepts, thus maximizing their potential attractiveness.

It should be noted that the project evaluation and comparison techniques presented here offer a very flexible format for examining alternative energy technologies. In addition to the technical, cost and market uncertainties captured in the models and data described above, one can represent environmental and regulatory uncertainties through the structure of the program decision trees by identifying potential regulatory actions as decision points with a range of potential outcomes. The extent to which potential environmental and regulatory actions are major cost or risk drivers can be quantified, and programs can be devised and examined which minimize the possible adverse effects. The approach summarized here is also flexible with respect to the level of detail employed. Useful information for program evaluation and formulation can be derived even with very simple applications. The level of detail desired tends to develop as the technology evolves. It may also occur that at different times greater detail is desired for different parts of the system model, that is, it is possible to treat some parts of the analysis in a great deal of detail, while maintaining the remainder at a "higher level". This approach provides a sound basis for evaluations of many different types, from preliminary assessments of new concepts to comparison and selection among alternatives through monitoring of the results of subsequent program phases of those programs selected.

[Examples are drawn from evaluations which have been conducted to date in the following areas: fusion energy (both magnetic and inertial confinement), solar power satellites, synthetic fuels, electrical storage and solar cells.]

ABSTRACT

RENEWABLE AND APPROPRIATE: KEY TO A TRANSITIONAL ENERGY FUTURE

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INTRODUCTION

The transition from a fossil-based to a renewable energy future must eventually occur when nonrenewable energy sources are depleted. To allow this transition to occur "naturally" could have disastrous impact on the world economy, environment, and overall standard of living.

There are numerous methods to affect how this transition takes place. This paper assumes that regardless of the specific set of projections used, an untenable situation results within approximately two generations if nothing at all is done.

The energy transition approach presented has four basic thrusts: (1) harmonization, (2) appropriateness, (3) decentralization, and (4) distribution. These attributes are merged in an energy future that; (1) satisfies supply and demand at the renewable energy source whenever possible, and (2) incorporates innovative energy distribution systems that combine soft and hard technologies to alleviate divergent supply and demand requirements.

FUTURE PROJECTIONS

Energy forecasts, whether they be supply/demand or economic, are fraught with uncertainties. The accuracy of these projections must be judged with the knowledge that, (1) the price of crude oil almost doubled last year, and (2) DOE projections in the 1978 report to Congress for the 1985-1995 timeframe were incorrect by a factor of two.

Supply and demand projections are not any easier to make since they are in large part interrelated with the cost of the energy produced and used. A simple fact must be realized; depletable energy sources have a finite life and therefore cost and supply are subject to large fluctuations. Conservation will only delay the date that these sources run out. The great majority of proposed synthetic fuels will not really alleviate the problem since these fuels are really a change of energy form (coal to oil or gas), not a replacement for fossil fuels.

Fusion energy is touted as the "limitless energy source" that will solve the energy crises. There is also a problem with this line of reasoning. Energy consumption creates heat that directly impacts the delicate temperature balance between incoming solar radiation ($1.37 \text{ kilowatts/m}^2$) and the amount of heat that is reradiated into space. The average temperature of the Earth cannot be increased more than a degree or two Centigrade without severe changes to ocean level, cloudiness, and

rainfall. Thus, we cannot afford any energy production that creates a larger heat load than one or two percent of the total solar radiation (174 million gigawatts). This impressive number is actually only a few hundred times present energy consumption. This causes a serious problem within two generations assuming present energy consumption rates continue as they surely would if the myth of the availability of an unlimited energy supply is perpetuated by development of fusion sources.

Whether the extinction of nonrenewable energy forms occurs because of physical or economic reasons is a moot point. A beginning must be made now to develop methodologies that will result in a smooth transition to renewable energy sources.

ATTRIBUTES OF A TRANSITIONAL ENERGY FUTURE

Harmonization

The long-term capital investment made in the development and use of traditional forms of energy makes it imperative that the mechanics of a harmonious transition to renewable forms be developed. Free market economies pay more attention to short-term benefits than to long-term social and economic costs. The "far future" for typical energy decisions is a three to five year payback. Relative economic costs far outweigh considerations of ultimate macro-costs which involve questions of long-term overall economic impact, total energy, utilization efficiency, long-term resource availability, and total environmental impact. It is precisely these considerations that must be integrated to develop the harmonization necessary to incorporate promising new energy options even though they may presently appear radical, uneconomical, or inefficient in the short-term. For example, energy production by burning natural gas is preferable to oil or coal-burning methods (directly contrary to current energy policy) since the transition to a "solar fuel", e.g., methane gas produced from organic waste and crops, is enhanced.

Appropriateness

The appropriateness of an energy form is directly related to overall efficiency of the energy use. Each energy conversion process reduces efficiency. Energy form and the ultimate end use must be considered on a regional basis. A large source of energy may not be collocated with a large demand for energy. Thus, either decentralization or methods of distribution play a part in the determination of overall appropriateness.

It seems painfully obvious that there must be alternative methods to obtain a temperature of 68° F (heat a house) beside creating the temperature of the sun in a nuclear reactor to boil water, which then is used to generate electricity, that is then transmitted hundreds of miles to the user.

Decentralization

As a nonrenewable energy source is depleted, the cost of producing it - and, therefore, the price to the consumer - rises progressively faster. This increasing cost for depletable energy sources and the escalating costs to recover and process the energy (mining, drilling, power plant construction) has fostered fewer, larger facilities. This centralization is increasingly subject to criticism as pollution standards become more restrictive and the loss of a few of these large generating facilities cripples large areas of the country. The present emphasis on large, central power generation to achieve economies of scale subjects renewable technologies to an unfair comparison. The "rules of the game" for renewables are different - smaller, more efficient, distributed power plants produce power as cheaply as large ones. They can be sited near the energy source and/or the energy user to simplify and economize the total energy generation system.

Distribution

Renewable energy sources are both dispersed (such as biomass, solar, and wind) and centralized (such as geothermal and hydro). Thus, the renewable energy source is not always available when and where there is a high demand. Innovative energy distribution systems can alleviate this problem.

One attractive distribution system is power beaming. Recent developments in laser technology make ground-based lasers attractive candidates for transfer of very large amounts of energy. Relatively small mirrors in orbit (5 to 60 meters in diameter) could transmit power via single or multiple bounces to any point on Earth.

Consider how coal-generated power from the eastern U.S. existing during off-peak hours could be "exported" to Europe or Japan thus using an existing "national resource". Or consider transferring geothermal or ocean-thermal (OTEC) power from Hawaii to the mainland and hydroelectric power from the Andes to North America. Perhaps the power from the wasted natural gas being flared away in Saudi Arabia and Mexico at the rate of millions of barrels of oil equivalent (BOE) per day or power from remote nuclear "parks" far from populated areas or power from solar arrays in the deserts of the world could be used to run lasers and beam the energy where the demand was greatest.

There are certainly many unanswered questions in this distribution method. The results of initial analyses are encouraging however. The exciting promise of putting the existing energy capacity in the world to better use and the ability to develop and use remote sources of renewable energy dictate serious consideration of this "marriage" between hard and soft technology paths.

SCENARIOS TOWARD ECOLOGICAL, ENTROPY,
AND DECENTRALIZED WORLD

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EXTENDED ABSTRACT

INTRODUCTION

All developed countries appear to be operated under an economy-energy-top down (centralized)-oriented system independent of capitalism and socialism. Here scenarios for a conversion into an ecology-entropy-bottom up (decentralized)-oriented system at regional, national and global levels are described based upon a concept of ecological world view. Here "ecological" is meant to minimize liability over a long term, be adaptive to nature, and do it ourselves.

SCENARIO TOWARD ECOLOGICAL WORLD

Urbanization, industrialization, pollution and demand/supply gap in food and energy resources in Japan represent a future global state of several decades ahead. Therefore, a new national plan of Japan issued in 1977 might give a suggestion to the coming 100 years of the world. "The river endlessly runs, and its water never returns". This prologue of the essay HOJOKI written in 1216 describes clearly both physical environments of the Japanese Archipelago and cultural characteristics of the Japanese nation. Watershed was the unit of living, and the culture was grown along the river for a long time. Japan was opened to foreign countries at the end of the 19th century and the Western civilization was introduced. The development during the past 100 years was equivalent to a shift from "culture along river" to "civilization along coast". It was accelerated after the Second World War, and an economy-energy-top down-oriented system was established. A significant feature of the new national plan in 1977 is a conversion into a decentralized system based on watershed structure, or the unit is called "habitat". It is remarked that this term is borrowed from ecology. Therefore, a regional planning or a bottom-up planning might have a priority. Negative planning or "What shall I not do?" rather than "What shall I do?" might be a basic principle.

SCENARIO TOWARD ENTROPY WORLD

In ordinary theory of economics, the driving force of social or economic activity is not clear. For instance, Marxian economists say that the surplus value of labor is the driving force. However, this proposition

is not correct because labor is a component of states of society. Generally, the system cannot be driven by its internal component, and the driving force is a resource supplied from the environment. Labor is not a driving force but a function for an effective utilization of resource. Therefore, an essential characteristics of social or economic activity is open system in which the input of resource and output of waste are existed. Two types of resources - high entropy and low entropy - are distinguished, in which typical low entropy resources are oil and water. Utilization of solar or nuclear energy - typical high entropy resources - is shown to be nonsense. A conversion into the minimum entropy production earth is outlined.

SCENARIO TOWARD DECENTRALIZED WORLD

Referring to the structure and behavior of aquatic microcosm ecosystem, the finite eco-social system with respect to space and resource availability is discussed. The microcosm contains bacteria, protozoa, chlorella, blue green algae, and rotifer. A significant feature of microcosm at the mature state is colonization. Unit colony of 2-3 mm diameter which contains a full set of organism is distributed uniformly as patches within the nutrient solution. A few characteristics are described as follows : (1) Colonization is significantly reproducible, (2) Stirring the system by one minute a day is enough to derive mature stage with homogeneous single community. However, the total numbers of higher trophic level are only 1/10 of the colonized microcosm. It is meant that the colonized microcosm can support much more amounts of organisms even if a nutrient condition is same for both cases, (3) At the mature stage, both gross production rate and community respiration rate are very low. Instead, the resistance of organism to poisonous chemicals and radiation is significantly high. The model microcosm is defined as a decentralized cooperative but inactive and poor system. A conversion from a competitive state toward a poor cooperative system is discussed.

DECENTRALIZED SOLAR ENERGY AND THE ELECTRIC UTILITIES

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EXTENDED ABSTRACT

The centralization of electricity production and distribution in the U.S. electric power industry results from the historical process of industrialization and is by no means unique to the utility industry. It has been mainly the achievement of scale economies in generation, distribution and organization, made possible in part by territorial franchises, along with general technological progress, that has brought about this situation. The benefits to society have been a reliable, versatile, and abundant energy source to fuel industrial growth and provide amenities to the general populace.

Recently, this system, along with many others, has been called into question as environmental stresses have increased, becoming more visible and of greater concern, and as the real cost of electricity, historically on the decline, has begun to rise. A frequently postulated alternative to the centralized system is a decentralized system of energy production which utilizes renewable energy resources. Such a system is believed by its advocates to have the attributes of environmental benignity and individual control.

The focus of this debate has unfortunately been on the attributes of one system versus the shortcomings of the other rather than on how each, together, can contribute to our domestic energy supply. The current vulnerability of our nation to an insecure supply of energy dictates that the domestic production of all forms of energy be our major concern.

Solar energy, although having great potential, has drawbacks. It is by nature an intermittent source of

energy and thus solar systems require varying amounts of storage capacity in order to provide currently expected levels of reliability. Dedicated decentralized energy storage is prohibitively expensive. At present, the high front-end capital costs of solar equipment are also a barrier to their rapid adoption by individual consumers. The long process involved in securing financing and locating a credible system installer can be a further hindrance.

The electric utilities are an ideal institution for implementing solar programs. The utility system is theoretically capable of providing the storage capacity required during the periods of solar shortfall. The utility also represents a potential source of capital for financing solar programs and provides an existing infrastructure to oversee system selection, installation, and maintenance. Some utilities are already conducting programs which are proving very successful in promoting solar energy and conservation.

A transition to a mixed centralized and decentralized energy supply system will involve technical, social, and institutional adjustments. Net energy effects will have to be considered. Despite the difficulties, decentralized solar options do have a role to play in supplementing conventional energy production and providing a potentially less environmentally harmful source of energy. However, by focusing on the centralization/decentralization issue, and excluding the electric utilities from involvement in the solar field, valuable time and effort will be lost for moving ahead with solar energy.

EARLY PLANNING FOR COGENERATION

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ABSTRACT

In studies for new generation, utility planners are considering means of providing for a source of heat for cogeneration should a customer be identified after a turbine-generator has been purchased. One scheme includes writing into the turbine-generator specifications a requirement for increasing certain extraction flows beyond the normal generating plant extraction steam flows. This is to accommodate presently unknown steam or hot water customers that might be identified after the turbine-generator is constructed.

EXTENDED ABSTRACT

The extent to which industry and utilities can cooperatively develop cogeneration can be influenced by utility planners.

The potential mutual benefit of cogeneration has been well documented. There should be little doubt that there are savings to be enjoyed through cogeneration under favorable needs and circumstances.

One major underlying deterrent to the successful mating of the electric utilities and industry is the long duration of the design, licensing and construction schedule of central station power plants.

These activities can exceed 168 months for large nuclear units and 106 months for large fossil units. These long lead times preclude meaningful negotiation between parties. By the time Industry recognizes a firm energy demand the Utility is financially committed to a specific design that may not suit cogeneration requirement.

For a successful cogeneration application, the steam turbine must be designed to suit cogeneration needs for steam conditions, process flow and electricity. A projection of the single parameter of electricity is uncertain enough without the added dimensions of uncertainty. The disappointing lack of progress in implementing cogeneration is no surprise to anyone who has faced this barrier of diverging lead times between parties.

Plants coming on-line today are generally not designed for cogeneration, and for plants being designed today, there is literally no one to talk to except ourselves. This paradox can be tempered to some degree in the early planning process.

Consumers Power Company recently completed an investigation of utilizing low level heat at our next unit. (Presently forecasted for the early 1990s). Our thinking was that perhaps we should be growing vegetables, or other foods, producing gasohol, drying grain - doing something to enhance the economics and utility of power production. It became apparent that there is only a philosophical interest in the energy available from our next unit. We cannot reasonably expect other industries to commit to the distant future and to share our uncertainties.

However, we did identify specific action that could be taken to encourage some unspecified cogeneration opportunity that may materialize in the future:

Site Selection - Power plant siting has become a highly sophisticated activity involving numerous environmental, social, political and economical parameters. While it is unlikely that an unspecified cogeneration opportunity will influence site selection, the selected site location will determine what future cogeneration opportunities might develop. For example, the trend towards rural siting while discouraging district heating may in fact encourage cogeneration requiring large acreage (eg, soil warming, greenhouses). Identifying the most likely type of cogeneration candidates can aid the early planning activities.

Space Allocation - Acreage can be dedicated in the conceptual layouts of all candidate sites at essentially no cost to the project. We have found that the area designated as construction laydown is ideally suited for an industrial partner. The size (approximately 100 acres) should suffice for a large segment of industry. The close proximity lends itself to either a hot water or steam supply. The land availability is ideal since the construction laydown area becomes idle just as the construction of a cogeneration facility becomes most likely. Should a coregeneration partner never materialize or be long deferred the area can be readily utilized as waste disposal.

Equipment Specification - At almost indiscernible cost we can incorporate flexibility into the turbine-generator specification. For example, additional uncontrolled extraction steam of 300,000 lbs/hr should not cause any significant design modification in an 800 MW unit. Similarly, providing multiple extraction ports at several steam quality levels adds essentially no cost to a power plant however, adding extraction ports to an existing turbine is generally a very expensive and difficult task.

From the standpoint of optimum thermal performance provision for larger extraction flows should be anticipated - however, at some point the Utility begins risking the stockholders and rate payers' money on the concept. In the future an economic advantage in energy cost will play a more significant role in the competitive position of any product which in effect begins to ensure future partners in cogeneration. Even significant investment in anticipation of cogeneration may prove justifiable as energy costs continue to increase.

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SYNERGISTIC CONSIDERATIONS IN SOLAR ENERGY--ANOTHER APPROACH

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EXTENDED ABSTRACT

Standard approaches for solar electrical power generation are visualized as vast desert tracks many square kilometers in area covered with solar cells. The support structure built to withstand 100 MPH winds, sand storms, and other severe conditions for more than 30 years is rapidly becoming a key economic parameter. This paper will compare the area utilization of solar power vis-a-vis coal, hydro, and nuclear, and show how the synergistic use of roof-top solar systems owned by the utilities can serve the quadruple purpose of providing shelter, electrical generation, heat generation, and night radiative cooling. Such systems would be connected to the electrical grid through switching power supplies, alleviating the demand for local electrical storage while utilizing double hot and cold cisterns for storage of thermal heat and cooling water. It will be shown that the average home and factory roof coverage is sufficient for total per capita power generation, and the reduced air conditioning load provides for economical net per capita energy cost.

TECHNOLOGY ASSESSMENT OF SOLAR ENERGY
"AN EVALUATION OF WIDESPREAD DEPLOYMENT
OF SOLAR AND BIOMASS TECHNOLOGIES"

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EXTENDED ABSTRACT

The Technology Assessment of Solar Energy (TASE) was designed to establish a framework in which to understand the environmental and socioeconomic consequences of solar energy in the year 2000. It must be kept in mind that the rate of solar growth implied by national energy programs leads to the conclusion that the major increase in solar in both scenarios occurs between 1990 and 2000 and is heavily skewed to the end of that period. As a consequence, both scenarios represent a snapshot of a highly dynamic solar growth situation and not a steady state national energy mix. Under the assumption of a continued aggressive national solar program in the early part of the 21st century, the solar fraction of the national energy mix would undoubtedly stabilize at a greater number of quads. However, neither the assumptions implicit in the DPR or other national fuel policies permit more than speculative analysis beyond the turn of the century. On that basis, the most salient feature of the study is likely to be the implications of the growth trends of the pollutant and resources parameters into the 21st century.

The analysis of the high and low solar scenarios, concluded, that for the parameters studied, the positive and negative national environmental and socioeconomic impacts of solar energy are generally small when compared with the influences of conventional energy sources and other elements of the economy. However, the study did identify several potentially significant environmental and socioeconomic benefits, disbenefits and tradeoffs. Furthermore, the environmental benefits associated with solar technologies will not be maximized given economic incentives only, but are very sensitive to the solar technology mix, conventional fuels displaced and siting. For the scenarios studied, capital-intensive direct solar technologies tend to have significantly smaller direct environmental impacts during normal operation than the nonrenewable technologies that they would replace. The study also concluded that biomass, in particular

uncontrolled small-scale, wood stoves and agricultural residue combustion systems, tend to significantly increase the particulate pollution levels in regions where they would be sited. This situation could generate significant air pollution, health and visibility problems in certain regions and localities.

The following summarizes significance of the results of the analyses performed.

- Air Quality - significant increases and decreases in energy related criteria pollutants; minor influence on long-range transport of energy-related pollutants; moderate regional decreases in SO_x and NO_x ; significant increases in biomass-related TSP in certain regions and subregions; minor changes from nonenergy related criteria pollutants associated with manufacturing solar on a national basis.
- Water Quality - relatively minor increases and decreases in water pollution nationally; some significant increases in erosion in agricultural states; some potential local benefits and disbenefits associated with reduction conventional waste disposal requirements and increased solar working fluid use.
- Water Resources - nationally insignificant especially in the eastern U.S., but with some potentially local problems in the west associated with discretionary water use for solar systems; and local benefits in the east associated with reduction in mandatory water use from conventional power plants.
- Land Resources - on site solar energy demands can be exceeded in all but the most dense land use sectors, this would offset adverse local land use impacts, but is highly influenced by local land use planning decisions.
- Indirect Impacts - because the scenario year occurs early in an extrapolated solar transition, indirect pollution is not estimated to be highly significant; however, solar growth rates required to achieve the high solar case, if projected into the 21st century, could make indirect pollution a significant problem in industrial areas in that period.
- Economics - significant additional energy related capital investment nationally, with an associated dampening effect on other areas of the economy; the distribution of the additional energy related investments have a more significant impact at the local level than comparative investments in conventional energy sources.
- Employment - minor increases compared to total national employment, but potentially significant as the rate of growth of solar energy accelerates in the late 1990's; significant increases in certain skilled labor categories with corresponding decreases in other labor categories.

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- Materials Resources - solar related materials requirements are significant in terms of total national requirements for several key industrial materials both domestic and imported.

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ENERGY PROGRAMS

THE ROLE OF SOLAR ENERGY IN THE LONG TERM U.S.
NATIONAL ENERGY PLAN

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Abstract

In recent years solar energy has received increasing emphasis as an important long term source of renewable energy for the U.S. A large portion of the public has become infatuated with solar energy and the solar program budget has increased from less than \$20 million in 1974 to nearly \$1 billion in 1980. Yet the actual potential for solar energy as a viable energy source for the United States has remained a topic of sharp controversy within government, industry and the research community. Solar energy proponents look upon it as an alternative to nuclear and fossil fuels and see any contentions to the contrary as evidence of a widespread conspiracy to suppress the development of solar energy. Others however, see solar energy as a little more than an idealistic fad and discount the potential for solar energy to contribute meaningfully in this Nation's energy program anytime in this century. The truth, as usual, lies somewhere in between. Last year, after the most comprehensive review of the problems and potential of solar energy -- the White House domestic policy review -- President Carter declared as a national goal that by the year 2000 20% of the Nation's energy would be derived from solar energy sources. This paper specifies the details for achieving this goal. We present year-by-year estimates of the required solar energy installations through the year 2000. Economic, political and social barriers to achieving these goals are discussed, and the levels of public and private financing required are estimated. The costs and benefits of developing solar energy technology over the next two decades are compared with those of developing synthetic fuels, nuclear power and other energy sources. Finally, the relative priority of solar energy in the Nation's energy supply mix over the next 20 years is described.

EVOLUTION OF WORLD ENERGY CONSUMPTION (1960-1976) AND
DEVELOPING COUNTRIES ENERGY CONSUMPTION FORECASTS (2000-2020)

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ABSTRACT

I. Evolution of World Energy Consumption (1960-1976)

This study aimed at elaborating for the 160 industrialized and developing countries forming the world community, a comprehensive reference base of the energy consumption situations for both years 1960 and 1976.

The domestic primary energy consumption of each country is expressed in tons of oil equivalent according to 9 supply sources :

- 4 commercial : solid mineral fuels, natural gas, oil,
primary electricity (hydraulic and nuclear energy).
- 5 non commercial : fuel wood, wood wastes, cereal straw,
vegetable wastes, animal wastes.

With the corresponding GNP per capita and population figures.

Commercial energy and fuel wood consumptions are derived from the international statistics (UNO, World Bank, FAO). As far as agricultural non commercial sources are concerned, they are calculated for each type of product through the general equation :

Energy consumption of the product i

agricultural production (i) X waste production coefficient
X energy utilization coefficient X calorific value of (i).

This is a first attempt to collect and harmonize coherent world energy data, taking into account the unknown field of non commercial supplies.

For this presentation, I could concentrate on developing countries and/or on non commercial energy situations only, as required.

II. Developing Countries Energy Consumption Forecast (2000-2020)

The objective of this study is to establish for a ten regions based Third World, energy consumption forecasts to the years 2000 and 2020.

This has been reached through 3 economic scenarios :

- (A) high growth of industrialized countries
- (B) slow growth of industrialized countries
- (C) rupture between North and South

derived from the main assumptions of the OECD report : "Facing the futures".

The methodology is new : a combination of global and sectoral approach to forecast income elasticities through quantitative and qualitative variables.

The results are given for ten regions according to ten different sources :

- 5 commercial : solid mineral fuels, natural gas, oil,
hydraulic energy, nuclear energy, "new" sources.
- 5 non commercial : fuel wood, wood wastes, cereal straw,
vegetable wastes, animal wastes.

The results underline the progressive leading role of LDC's in the formation of future world energy demand ; they show the regional differences within the Third World, the emergence of nuclear and new sources ; and confirm the critical part played by oil in developing countries economies during the transition period which separates us from the time of abundant resources.

RECENT DEVELOPMENTS IN THE ALTERNATIVE ENERGY SCENE IN INDIA

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EXTENDED ABSTRACT

While Professor Adelman's prediction that the OPEC cartel would collapse has not so far come true, the forecast of Sir John Hill, Chairman of the U.K. Atomic Energy Authority, that the world price of fossil fuels would double in real money terms soon, has been fulfilled in more than an ample measure. The hike in the OPEC oil price has had a crippling effect on India's economy and the country's sixth five-year plan has been recast after the new Government came into power early this year.

The oil import bill of India which was Rs.2,804 crores in 1978-79 and Rs.1,654 crores in 1977-78 has risen to Rs.5,000 crores in 1979-80, a three fold rise in two years. In a few years, it is feared, it might go up to Rs.11,000 crores and it would require herculean efforts to earn at least twice this amount through exports.

It has been estimated that for an Indian population of 1,034 million by the turn of the century and a per capita GDP of Rs.1,025, the energy demand would go up from 392 mtce (million tonnes of coal equivalent) in 1970 to 1,150 mtce by 2000 A.D. In other words, for a rise of per capita GDP by one and a half times, the energy demand will rise three times. Development is highly energy sensitive.

The Government's Working Group on Energy recently forecast that the crude demand by 2000 A.D. would rise to 92 million tonnes per year, whereas the total reserves (inferred and proved) are at present around 175 MT. Two recent discoveries, one of an oil-gas field of considerable significance in the Narasapur area of West Godavari District in Andhra Pradesh on the east coast, and another of high grade coal deposits amounting to as much as India's existing reserves of 1,11,800 million tonnes deep under the ONGC's Kalol and Mehasana fields in North Gujarat, have brightened the hopes in the energy sources. But this may not, in the long run, alter the demand-supply ratio for crude and India may yet remain a net importer of oil.

This position has been well understood by the Government and the recently released draft outline of the Sixth five-year

plan(1980-85) shows an outlay of Rs.25,650 crores on 'Energy', which works out to 28.5 per cent of the total outlay of Rs.90,000 crores in the public sector, compared to the outlay of Rs.19,612 crores for the same sector in the 1978-83 plan of the previous Government. The new energy policy has a three-pronged thrust: a deliberate shift towards a less intensive model of growth, positive steps to achieve more efficient use of energy and its conservation and development of alternative energy sources. In fact, the plan draft mentions as its minimum objective in the energy sector the development of extensive use of solar energy by the end of the decade for irrigation. A cabinet panel on energy has been set up which, among other things, would look to the development of alternative energy sources. For the development of solar energy, the allocation has been raised to Rs.65 crores from Rs.25 crores. A major solar power centre has been proposed to be set up at an estimated cost of Rs.60 million over the five years.

Among the solar gadgets developed may be mentioned a ten-tonne per day capacity solar grain dryer, solar dryer for cash crops such as tobacco, ginger and turmeric, solar heating systems, a 40 watt solar panel using 40 silicon solar cells, a 10 kv capacity solar thermal plant, solar photovoltaic modules and distillation plants. Under a major national programme, all these gadgets are to be subjected to field trials.

About 80,000 biogas plants are in operation in the country. Under the sixth five-year plan, it is proposed to install 6.5 lakh biogas plants in various parts of the country. There is, however a serious apprehension that the poor man in the rural area is being deprived of the common fuels, cow dung and firewood. The socio-economic effects of excessive and improper use of gobar gas is being studied. A new device to produce power from cow dung directly has been devised in Tamil Nadu Agricultural University.

The Geological Survey of India has finalised a five-year programme to survey the geothermal capacity in the country. The Tamil Nadu Electricity Board's proposal for an off-shore power plant(OTEC) that will generate electricity from sea water is being considered seriously by the Union Government and it is estimated to cost Rs.50 crores, exclusive of the submarine cables which would cost about Rs.20 crores.

There has been a significant development in the MHD field. A prototype MHD plant designed and fabricated jointly by the engineers at the Bhabha Atomic Research Centre and the Bharat Heavy Electricals Limited was recently tested successfully. The Indian design is based on coal, a commodity which the country is richly endowed with. A pilot plant is to be built at Tiruchi in Tamil Nadu for further work.

The coals of North Assam are reported to be suitable for hydrogenation. The need to intensify the programmes to liquefy and gasify coal and also to launch a programme to introduce hydrogen as India's future fuel, was emphasised at the recent session of the Indian Science Congress in February 1980.

Successful tests have been conducted only a few days ago using ethanol to operate a 1,100 cc and 1,489 cc car in Madras. India is one of the largest producers of sugarcane in the world and could get 500 million litres of alcohol from 27 lakh tonnes of final molasses. Could gasohol be the answer?

Better management of India's animal resource is envisaged, estimated at 240 million cattle of which 70 million are bullocks. There are more than 13 million bullock carts. Their performance is to be improved with better cart designs. Besides, proper utilisation of and development of the inland water ways, coastal shipping and efficient road transport are envisaged as some of the measures for conservation of the non-renewable fuels and energy sources. Low cost wind mills have been designed at CAZRI, Jodhpur. Introduction of social forestry and other afforestation schemes are being emphasised in the plan programme not only to meet the fuel needs of the rural population but also in the larger context of prevention of soil erosion and flood control. Water hyacinth and other varieties are to be tested for large-scale use as energy sources.

It can be said that India has launched well on the programme of development of alternative energy sources.

A MATHEMATICAL CAPITAL PROGRAMMING MODEL FOR ELECTRIC ENERGY

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ABSTRACT

The research deals with the construction of a multiperiod mixed integer programming model for the capital programming and planning optimally operating pattern of the electric power generating plants. Some relevant observations are made to specify the special structures.

Essentially, three different types of power plants, namely, hydro-electric, nuclear and thermal plants, are investigated within the model framework. Through the various types of experimental solutions derived from the model, the questions of what type of installations at what capacity, the introduction and scheduling of the conventional thermal plant capacity, and the planning of power outputs of the different types of plants are approached to find an optimal arrangement (solution).

The model is attempted to apply to the case of Turkey to analyze electrical power generating sector. Some simulation experimentations and sensitivity studies are made. The findings and conclusions are summarized.

COMPUTERIZATION OF ENERGY SYSTEMS USING MODERN SYSTEMS
TECHNIQUES - PERSPECTIVES, PROSPECTS & STRATEGIES FOR
ECONOMIC DEVELOPMENT. PART I.

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ABSTRACT:

The survival and progress of modern civilization is dependent upon the phenomenon of energy. The cost of procurement of energy is increasing rapidly as is the cost of the associated technology to produce it. The developed nations have begun a process of redeveloping to meet the new challenge as a result of the change in the international energy scenario. Their redevelopment is guided by making more sophisticated use of energy and material resources & eventual reduction of the per capita energy requirements with potentially improved social & environmental conditions. While the industrialized or redeveloping countries are changing their trajectory, the developing nations must look to new models to guide their own economic development. Instead of expanding existing energy networks in response to increasing energy requirements, as has been done traditionally in the West, the developing nations should take advantage of existing modern systems modelling techniques with the objective of adapting them to their individual needs & objectives. Such an approach has the potential of lowering the cost of energy, contributing to new systems planning &

design techniques in the applied research effort at the global level and improving the performance & reliability of energy systems. This paper is the first part in a series of publications designed to expose & update engineers, system-scientists, energy economists & technocrats to some of the modern systems techniques available for energy systems planning, with the overall objective of growth in economic development, especially for developing countries. This paper is intended to have considerable tutorial value to experts in the energy area as it is designed with the underlying guideline of (i) modern technology transfer and providing (ii) a quantum increase in the awareness of some system techniques for energy management & planning at the international level. Part I of this series reviews the global energy scenario, discusses possible energy related alternatives & strategies faced by developing economies and deals in this direction with the subject of computerization of energy systems using optimum strategies.

SUMMARY:

A recent study [2] by the International Institute for Applied Systems Analysis on the subject of Global Energy Supply & Demand for the next 50 years puts into perspective the gravity of the international energy scenario. This study showed that time will be the limiting constraint in adapting the energy supply infrastructure to changing resource availability with resources being available until the second half of the next century, thus requiring a definite shift to alternative sources of energy.

While the effort for developing alternative energy sources continues at a hectic pace, one must also accelerate the optimum utilization of existing resources. This is possible typically through an identification of problem areas which could lead to large scale curtailment of services for extended periods of time. The economic consequences and associated drop in GNP or such an unavailability of energy is well documented in the literature

DEFINITION OF THE PROBLEM:

Developing countries are beset by power system problems which result in recurrent power failures (blackouts) and frequent variations in frequency and voltage with resulting damage to customer equipment. Overloading and insufficient generation availability owing largely to inadequate system planning techniques are among the major contributors, besides the exogenous factors involved.

PROPOSED SOLUTION TECHNIQUE:

Computerization of electric energy systems can greatly facilitate in alleviating some of these difficulties. However, computers cannot do the job effectively unless a well defined mathematical modelling project, based on state of the art techniques, is taken into consideration. Networks, such as Power Systems in developing countries as in PAKISTAN are among some of the networks faced with these type of difficulties. Techniques from Systems Engineering such as construction of power system state models and optimization models based on mathematical programming lend themselves well to the prospective overall solution of the problems discussed.

Currently, many of the networks in developing countries are dispatched at best based on the classical ECONOMIC DISPATCH, if at all. The question of incorporating power system SECURITY into the dispatch methods is a remote, if not foregone proposition.

In the following, computerization of electric energy systems is proposed through the use of the OPTIMAL SECURE DISPATCH for the interconnected network. The formulation efforts in the literature are scattered and at best sketchy. This paper represents a comprehensive research effort at integrating with new research some of the more useful state of the art techniques available in energy systems engineering and adapting them to the formulation of the dispatch problem not only for economic & secure operation of the system but also taking into account the availability of energy.

The end result is an optimization model which incorporates an optimal dispatch strategy incorporating features such as economics, system security & reliability and availability of energy supply which has become a very important factor in present world energy conditions.

MATHEMATICAL PROGRAMMING FORMULATION OF THE PROPOSED MODEL:

The optimum Dispatch Problem stated in mathematical programming format using compact state space notation is

$$\min_{\mathbf{u}} F(\mathbf{x}, \mathbf{u}) \quad (1)$$

$$\text{s.t.} \quad \mathbf{g}(\mathbf{x}, \mathbf{u}, \mathbf{p}) = 0 \quad (2)$$

$$\mathbf{h}(\mathbf{x}, \mathbf{u}, \mathbf{p}) \leq 0 \quad (3)$$

where

- x is a vector of dependent controlled variables
- u is a vector of independent control variables
- d is a vector of perturbations or disturbances.

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CANADA'S ENERGY PICTURE: PROSPECTS FOR RENEWABLE AND
NON-RENEWABLE ENERGY SOURCES

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EXTENDED ABSTRACT

Over the past few decades, North America has had abundant supplies of cheap, convenient energy. Effective use of these has led to innumerable social and economic benefits, and has contributed to the current high standard of living in Canada and other western industrialized countries. Because much of this energy has been supplied by oil in recent years, we have developed a society which is critically dependent on petroleum resources. In the early 1970's, Canada was a net exporter of crude oil but in 1975 it became a net importer. With domestic oil production peaking in 1973, Canada has now come to rely on imported oil, which is increasing in price at an alarming rate. This situation must be changed and alternative energy sources developed in order to meet future energy requirements. This paper reviews Canada's renewable and non-renewable resources and assesses the potential of each in contributing to future energy demands.

Oil dominates Canada's current energy picture and that of many other industrialized countries. In Canada, oil accounts for ~45% of the total primary energy used and ~60% of the secondary energy. Most of the remaining energy comes from natural gas and hydro power. Canada's per capita energy consumption is one of the highest in the world, a result of the high post-war growth rate in total primary energy consumption. The growth rate was ~5% per annum between 1950 and 1975 and ~3% per annum since 1975. Energy demand will likely continue to increase in the future, though probably at a slower rate than that over the past 30 years. However, even a modest 2% annual growth rate will result in a 50% increase in total energy demand by the year 2000. Canada is therefore in a position similar to that of many industrialized countries, which must expand energy supplies to meet a small annual growth in demand, while reducing their dependency on oil, particularly imported oil.

Fortunately Canada, almost unique among the industrialized nations, has sufficient resources to reduce and eventually

eliminate its dependency on imported oil, and to achieve the national goal of energy self-sufficiency. A survey of the reserves of both renewable and non-renewable energy sources shows Canada's immense potential. Of the depletable energy forms, coal reserves (proven reserves plus estimated additional reserves) could meet today's total energy requirements for at least 40-50 years. Uranium reserves, used in the CANDU once-through nuclear fuel cycle, have approximately the same thermal potential as coal. However, if the reserves of uranium and thorium are used in more efficient fuel cycles, they could supply the thermal equivalent of Canada's current energy needs for at least 1000 years. Since electricity is a suitable replacement for oil in many applications, nuclear-generated electricity could play an important role in meeting the increase in energy demand. Canada also has a large renewable hydraulic resource, which currently supplies almost one quarter of the total primary energy consumed. Since there is potential to double hydroelectric generating capacity, it will undoubtedly be developed further and will continue to play an important role in Canada's energy future. Natural gas reserves are sufficient to bridge the gap during the conversion from oil to other energy sources. Oil from the tar sands represents a vast resource which offers Canada long-term security in essential liquid fuels. However, its rate of exploitation is such that it will not contribute significantly to Canada's total energy consumption until at least the 1990's.

The extent to which other energy sources will contribute is less predictable, at least during the next 20 years. Forest biomass already contributes about 0.35 EJ (~4%) of Canada's total primary energy consumption, virtually all of it in the forestry industry, and this contribution will likely double by the end of the century. However, although biomass resources are large, with potential for direct use or conversion to other fuels, they will probably not make a significant contribution outside the forestry industry during this time period. Solar energy has a large future potential but, unless the costs are reduced substantially, its use will probably not expand markedly in the next 20 years. Other renewable resources, such as wind, tidal and geothermal may be important in local areas but will not make a large contribution on a national scale.

In summary, indigenous coal, natural gas, hydraulic and uranium resources give Canada an opportunity to reduce its dependency on oil and to achieve energy self-sufficiency in the future. These resources are sufficiently extensive to last well into the next century, and their technologies are well-established. This will allow a careful assessment of

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alternative energy sources for the future, the most successful of which will supplement and eventually replace some non-renewable energy forms. There will be sufficient time to develop new technologies, for example, advanced nuclear fuel cycles and tar sands oil recovery, and to refine existing technologies to give improved efficiencies and reduced costs, e.g. solar power. This gradual development and incorporation of alternative energy resources will cause minimal disruption to society. However, decisions must be made and implemented now, if Canada is to lay the foundations for a future with its energy options secured.

ECONOMY IN ENERGY THROUGH ALTERNATIVE
SOURCES OF ENERGY IN MASS-HOUSING OF
DEVELOPING COUNTRIES

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EXTENDED ABSTRACT

INTRODUCTION

Energy is an integral part of the development process and a major determinant for the improvement of the quality of life in human settlements. During the past decade there has been an increased concern over problem of energy shortage and possible of the rapid depletion of fossil fuels. Skyrocketing oil price increases in recent years has made development increasingly difficult for at least two-third of developing countries. An increasing number of developing countries are searching for new sources of energy and more efficient use of what is available. Energy is not a short - term problem and we are not going to have a short - term solution. This problem makes consideration of various alternative energy sources a matter of great importance. Therein lies the value of well thought out comprehensive energy conservation program.

ECONOMY THROUGH DESIGN

The building uses over 30 percent of our total energy resources, and much of this has been wasted through traditional design techniques. As such they are the prime target of energy conservation. Considerable savings of energy should be achieved in the planning of new settlements.

To conserve energy in building means a new approach to the design process. Designing does not involve high technology. It is not a quantum physics. Since it is a straightforward technology, it involves such variables as local climatic conditions, surroundings and topography, trees and environmental values of plantation, the building site, the shape, orientation, height of the ceiling and proportion of openings. Through these areas there is a greatest scope to reduce the usage of energy in mass-housing. Recent investigations show that for the construction of new buildings total energy consumption could

be reduced by 20 percent by selecting less energy-intensive building materials.

INSULATION

The heating or cooling requirements for a building are because of solar radiation plus human activity in the area. The thermal performance of the building should be of prime consideration in the original planning phase. Further the paper discusses the most important factors in the design of a building shell, i.e., the insulation and fenestration, and recommends the utilization of solar energy for space cooling, space heating, and water heating. Because solar energy is by far the most abundantly available renewable resource, particularly in tropical regions of the developing world.

DESIGNER & ENERGY CONSERVATION

Meanwhile, the paper also examines the responsibility for conserving energy in new building design, which lies in the hand of architects and engineering professionals who are engaged in building industry. The professional design team must be aware of the new innovative concepts in energy conservation. But at the moment, the architects and engineers are the least qualified people to make such decisions.

The following important programs should be available to the designers so that they can design a much energy-saving house:

(1) To determine how people live in an environment for health, comfort and productivity. (2) An energy conservation design manual for every climatic zone in the country. (3) Solar table on sun angles in relation to building surfaces of various orientations. (4) A data bank which can provide all the informations and new techniques to apply to energy use.

Scientific and analytical studies are required on the complex inter-relationships between energy, on one hand, and various settlement parameters on the other, before making any policy decisions on the development of new settlement patterns. In building new settlements care should be taken to apply new and emerging technologies with a view to conserving energy and protecting settlements from the changing trends of energy economics.

LIGHTING & COOKING

Lighting and cooking are two other areas where some savings could easily be made. The paper suggests how the usage of energy could be economised in the field of lighting, cooking and hot water usage. The paper also examines and recommends for adoption of some of low-impact technology

for cooking purposes.

EDUCATION

A comprehensive public education program on the need for energy conservations should be launched by the Government. The paper strongly recommends that Universities and Colleges should teach the latest concepts of energy conservation and use of alternative energy sources. Besides, all the children should be taught about energy and energy conservation in schools for, they may have to face a much more difficult energy situation towards the end of the century.

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ENERGY: A COMMUNITY CONCERN
RURAL PERSPECTIVES FOR THE PACIFIC

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EXTENDED ABSTRACT

INTRODUCTION

Dramatic changes in the world's energy supply and demand patterns have provided urban planners with an opportunity to recreate the classical paradigm of planning. Shifting from a context of energy abundance to one of energy scarcity requires a corresponding shift in strategy and value-orientation. A goal of effective management of existing and potential energy resources projects the planner into a dimension where solutions must be sought from those whose experience is scarcity. Planning to meet the needs of the energy-deficient communities may provide the focus and clarity necessary to address the complexities of more industrially developed societies.

ENERGY TECHNOLOGIES ENTER THE PACIFIC

The rising cost and diminishing supply of fossil-fuel based energy is having its most profound effects upon the island nations of the Trust Territories whose survival has been entrusted to the United States for the past thirty-five years. Unlike the developing nations in Asia, Africa, and South America, that are experiencing the cultural upheaval associated with the transition to modern technologies, many of the Pacific islands' cultures have been irreparably damaged by the principles of Western technological development. Traditional lifestyles associated with fishing and indigenous crop farming have been abandoned in favor of the consumption intensive values of a service-oriented economy. Introduced needs created a new demand for fossil-fuel based energy which has been instilled into the everyday lives of the people. In many instances, the traditionally self-sufficient island communities are no longer capable of providing for their own basic needs because of their increasing dependency upon modern technology.

THE PACIFIC CONTEXT

The island nations of the Trust Territories provide a unique opportunity for energy resource development planning and management. However, the inherent differences associated with island life require a fundamentally new approach to problem resolution. In addition to their physical and economic isolation, Pacific islands lack the financial and informational resources necessary to cope with their developmental needs. Local cultural values may lead to irreconcilable constraints in terms of the planner's objectives and a limited range of viable alternatives. This is primarily true because a majority of the planners in the Trust Territories are western trained and bring Western ideas into the region.

CURRENT ATTEMPTS THROUGH RATIONAL PLANNING

Energy development planners, on the whole, do not yet have the necessary approach to incorporate social/cultural concerns into formal development models in a satisfactory manner. In order to understand the factors preventing effective rural energy planning, it is necessary to review the current process in which decisions are now being made.

One of the primary inadequacies of the current development planning arena is the use of the traditional rational planning approach. Experience has shown that the rational planning process breaks down at the point of implementation. The transition from the rational plan to the application of that plan more often than not is never quite accomplished and the plan ultimately fails. This failure is primarily due to the weakness of rational planning with respect to integrating the human factor into the energy development strategy.

AN ALTERNATE APPROACH: HUMANISTIC ENERGY PLANNING

Humanistic planning is the logical evolution of rational planning to incorporate the increasing recognition that the social factor of planning is as worthy of attention as the economic, legal, and environmental factors. The Humanistic approach accomplishes this by recognizing the significance of client-oriented plans which stem from planning 'with' the people instead of planning 'for' them or 'at' them. Through this approach, energy development can be led by the people, not by the technology.

The following is a brief summary of the individual steps of the Humanistic Planning process. Local participation is the most essential element in each of these steps in order to guarantee a higher degree of successful energy plan implementation.

Step 1: Identify the client. This step attempts to go beyond the traditional identification of a problem by recognizing who it is that the planner is planning with. The problem being addressed must be viewed from the client's perspective and to do this the planner must seek to understand the client's values.

Step 2: Identify the client's constraints. The Humanistic planner must attempt to identify the constraining factors with which the client is faced. It becomes necessary in this step to distinguish between constraints which can be overcome and those which must be planned around.

Step 3: Determine a range of alternatives within the identified constraints. As in the Rational mode, a range of alternatives needs to be identified. However, in the Humanistic process the range is limited to the area within the identified unremovable constraints of the client.

Step 4: Covaluate each of the alternatives. The term, covaluate, refers to the incorporation of the clients' values in the evaluation of the alternatives. It becomes essential at this step that the alternatives are weighted from the perspective of the client and the expertise of the planner, who recognizes

the biases of his own values.

Step 5: Select and incorporate the appropriate alternative. This step is similar to the Rational process except for the emphasis on *incorporation*. The Humanistic planner seeks to incorporate or blend the appropriate selection into the existing fabrics of the community/environment.

Step 6: Coevaluate and monitor. The process of studying the impacts of the selected alternative is again done from both perspectives: the planner and the client, as is the un-going monitoring procedure.

APPLYING HUMANISTIC PLANNING TO ALTERNATE ENERGY DEVELOPMENT

The incorporation of *appropriate alternate energy resources and technologies* into the energy mix of the Trust Territories necessitates the determination of what is 'appropriate'. To determine what technologies may be appropriate for the Pacific, or for that matter, for industrial countries, the first steps are to identify the limiting resources of production and the most plentiful resources, the social goals, cultural constraints, and perceived needs of the people. Identification of these factors is best achieved by the people of the region, therefore making their input a crucial element in successful energy development.

As the strategy of energy development planning elevates and prioritizes basic needs, the role of participation will become crucial to successful implementation. When planning includes participation of communities, a form of Humanistic planning occurs. Thus, the concepts of appropriate alternate energy resources and technologies are congruent with the philosophy behind Humanistic planning.

DEPARTMENT OF ENERGY SMALL SCALE ENERGY TECHNOLOGIES
IN AMERICAN SAMOA

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EXTENDED ABSTRACT

INTRODUCTION

In 1977 the Buildings and Community Systems Division of the Department of Energy (DOE) offered the Appropriate Energy Technology (AET) Grants Program for distributing grants for small scale energy producing systems. The systems should meet local demands, be compatible with local environments, be easily demonstrated and replicated elsewhere, and use local renewable energy resources. Through one pilot program and two national programs DOE has awarded grants for designing, constructing, and/or demonstrating a variety of energy producing and conserving systems. Average grant size is about \$15K.

The Program is funding about 175 projects in Federal Region IX (Arizona, California, Hawaii, Nevada, and the Pacific territories). There are 30 projects in the Pacific territories, which include American Samoa, the Commonwealth of the Northern Marianas Islands, Guam, and the Independent and Federated States of Micronesia. The Lawrence Berkeley Laboratory has been providing DOE with technical assistance for the Program, and one task is to monitor the Pacific territories' projects, offering technical advice and assistance. This paper reports on our observations from our most recent Pacific trip to American Samoa in the spring, 1980.

American Samoa consists of seven islands of the Samoan group east of the 171st meridian of west longitude and between 10° and 15° south latitude. The main island is Tutuila (135 sq. km), the site of the principal town and administrative center, Pago Pago, which is located on one of the best natural harbors in the South Pacific. Population of American Samoa in 1977 was 30,600; with 30,000 people living on Tutuila and 11,000 of these living in Pago Pago (1).

American Samoa became a Territory of the United States in 1900 when a commission consisting of Germany, Great Britain, and the United States agreed that the only way to provide a stable government for the politically turbulent Samoan Islands was to annex the Islands. As a Territory American Samoa is a separate political entity with its own legislative, judicial, and executive branches.

The Samoans are Polynesian, live mostly in rural communities, and structure

their lives around a social system of clans or extended families with chiefs. Unlike other South Pacific islands which depend on exporting copra for an economy, American Samoa has developed a relatively strong economy based on a thriving fishing industry. The Star Kist and Van Camp canneries, located side-by-side on Pago Pago Bay, are the largest private employers.

For their energy production American Samoa depends completely on importing petroleum products from Union Oil and Standard Oil of California. The fossil fuel end use is as follows: 51% for the fishing industry and other marine activities, 16% for generating electricity, 24% for jet fuel, 5% for automobiles, and 4% for other uses (2). Five diesel generators produced a peak output of 12,000 kilowatt-hours in 1978, and in 1976 they produced a total of 65 million kilowatt-hours (3). To decrease their vulnerability from petroleum supply disruptions, the American Samoa Government has adopted a six point plan, one part of which includes developing alternative energy producing resources and conservation measures through their Territorial Energy Office (TEO).

The TEO is studying a number of resources such as biomass, solar, wind, geothermal, and hydroelectric, but they are encountering some problems, a few unique to American Samoa, developing these resources. Ninety-five percent of the land is held communally and handled through customary Samoan ways. There is not much flat land on Tutuila, and therefore space for energy systems may be a problem. Because of tropical problems such as corrosion, storms, and lack of supplies, engineering is difficult, but there are not many engineers on American Samoa. There are also not many people with the technical knowledge to help the Samoans compete for federal grants. Samoans, with increasing outside contact, are acquiring a more energy consuming lifestyle and may be reluctant to return to traditional less energy intensive customs (4).

Despite the variety of resources and the aggressive energy policies of the TEO and the American Samoa Government, there are only a few alternative energy producing devices on the Islands. In 1978 the government arranged for a contractor to install solar hot water units on over 100 public and government buildings, but they have cancelled this program, and most of the units are not working. There are a handful of domestic solar hot water systems and a few methane digesters for animal wastes on outlying farms; this is the extent of alternative energy devices at present, although these are plans for testing some wind machines and installing a solar hot water system on the hospital.

PROJECTS

DOE is funding three AET projects on American Samoa. For the first project, in 1979 DOE awarded the TEO and a Hawaiian consulting firm \$20,000 to study converting tuna sludge to methane gas commercially. The two canneries dispose of about 20 to 25 million liters of waste tuna sludge per year. The sludge is hauled daily by trucks 15km to the other side of the island

and dumped into open pits, an environmentally poor method which is expensive and wastes gasoline. The TEO is using the grant to analyze the sludge for methane producing constituents, build and test a small digester for converting the sludge to methane, analyze the gas for methane content, and prepare an economic feasibility study.

The University of Hawaii has analyzed samples from both canneries for chemical oxygen demand, volatile solids, pH, and salt content. These constituents vary considerably over time suggesting that they collected the samples from different sources at the canneries. Samples from the Van Camp cannery have a lower salt content because the cannery uses a different process for thawing and washing the fish. Other samples have a low pH of around 4.5 which they have raised to 7.0 by adding sodium hydroxide to batches in the digester.

The test facility, built on the adjacent Marine Railway Authority premises, consists of a 200 liter digester and a 200 liter storage tank with a water seal. Construction is simple, using either local materials or parts built by the Marine Railway Authority. The digester seems to be working satisfactorily, converting about 50 liters of sludge to methane every two days.

In 1980 DOE awarded a \$1,100 grant to a scientist at the American Samoa Department of Agriculture to test and demonstrate an electric fence powered by a solar photovoltaic array. On outlying farms, farmers have a problem keeping wild pigs out of agricultural areas. Electric power does not service most of the farms, so the farmers do not use electric fences; regular fences do not work. Farmers are using photovoltaic powered electric fences on Western Samoa, but the system sponsored by this grant will be the first in American Samoa.

For the 1st project DOE has given the TEO a \$35,000 grant for constructing and demonstrating a Samoan Energy House. This house, which has been designed by the same architects who designed the University of Hawaii's Hawaiian Energy House, combines traditional Samoan fale construction with U.S. alternative energy producing and conserving devices.

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A B S T R A C T

Technology Assessment: Hawaii's Options for Transition to Non-Conventional Fuels

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The state of Hawaii has in the last eight years spent a considerable \$47 million in R&D for synthetic fuels. The quest to increase energy self-sufficiency through alternate energy sources has resulted in the emergence of both soft and hard technologies. These technologies are likely to be of significant importance in determining the pace and pattern of alternate energy source development.

The Hawaiian chain of islands is blessed with an abundance of alternate indigenous and potentially renewable energy resources such as - biomass, geothermal, solar radiation, wind and ocean thermal differences. Energy from these unconventional sources are likely to be costly. But the hard choices that have to be made between energy conservation, environmental degradation, public safety and high risk imports provide convincing and compelling reasons for their propitious introduction.

The development of these energy resources are likely to impact with future demand for electric and non electric energy in the state. To meaningfully evaluate the state's options for transition to alternate energy forms, this paper examines critically some inherent uncertainties as well as elements of timing and cost associated with such changes. The payoff to R&D expenditures is quantified by solving a linear programming model (A.S. Manne, 1975) to obtain minimum cost calculations for meeting future energy demand with and without a non-conventional fuel technology. The difference in above cost calculations refer to the size of 'benefit' resulting from the development of a specific technology.

The rationale for both governmental and industry participation in preliminary R&D endeavors is highlighted and suggestions for combining public funds with private initiative made.

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SESSION 6G

ECONOMICS AND POLICY III

THE IMPERATIVE OF RENEWABLE ENERGY SOURCES PLANNING
IN A NEW ECONOMIC AND SOCIAL ORDER

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EXTENDED ABSTRACT

Demand, supply and distribution of energy and natural resources - in a narrowly defined concept of the free market economy - is today one of the critical issues of "the planning for survival."

The age of scarcity is reaching crisis proportions with the rapid depletion of natural resources, the approach to "the limits to growth" and the "end of affluence."

Planning and implementation of radical economic and social changes coupled with the development of renewable non-polluting energy sources - for a gradual post-petroleum era transition - becomes an imperative for research and science and a challenge for modern technology "know-how."

The conventional fossil-fuel energy resources - except coal - with all shortsighted "technological fixes" will not last far beyond the half of the next century. Theoretically only the United States - with a six billion barrels of oil annual consumption - can consume within eighteen months, the entire known recoverable Alaskan oil of 9 - 10 billion barrels! (Within the frame of similar numerical calculations U. S. energy hungry economy can consume the entire known recoverable Middle East oil within 60 - 70 years - even without any further increase of the present oil consumption levels and rates!)

The imperative of renewable energy sources development and planning within a setting of a new economic and social order - to prevent an apocalyptic catastrophe and breakdown - is long overdue. The energy future of the world belongs to the sun's renewable energy sources: solar, wind, geothermal energy, hydropower and energy from oceans, biomass, biofuels and hydrogen gas. (Probably - and ultimately - controlled nuclear fusion.) Nuclear power and breeder fission reactors: the grave threat of "nuclear accident" and radioactive contamination. The implications of a renewable energy resources planning: social, economic, technological and life style changes and adjustments, are but a few of the basic changes.

ENERGY PLANNING FOR AN INDUSTRIAL COMMUNITY

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Comprehensive energy planning for an industrial community in this era of uncertainty of raw materials and explosion of possibilities requires careful analysis of the actual energy needs of the total community, a realistic projection of future growth, investigation of all possible alternatives capable of meeting these needs and development of an implementation program to complete all necessary actions. This paper details the development of an integrated Energy Use Plan for McClellan AFB CA, an industrial community of 3,000 acres and 16,000 people. It covers all areas necessary, including the community physical layout, mission requirements, regional energy situation and numerous alternative energy supply options. The basic concerns of this development were:

- a. Perform an energy audit of the community, develop a demand profile, and future consumption projections.
- b. Investigate all possible energy conservation and alternate energy source use options.
- c. Select a strategy combining all possible options which would fulfill requirements to decrease non-renewable energy use, increase the efficiency of energy use and decrease adverse environmental effects.
- d. Develop an implementation plan to successfully accomplish all necessary projects to bring the industrial community to a minimum energy use state by the year 2000.

During the course of this analysis, numerous site-specific activities were accomplished. An energy audit to develop baseline data on present energy use, conservation potentials, indigenous energy resources, environmental conditions and existing regional relationships and policies were performed. These data were then used to project conservation and consumption potentials to 2000. Possible conservation and alternate energy supply options were identified and evaluated within the constraints of the overall analysis. Those options surviving were then integrated into an overall plan in the most effective implementation order depending upon first and second order results as well as a set of feasibility factors. This was then developed into the

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energy use minimization strategy by inclusion of an implementation plan. The analysis also indicated that, if the plan were fully implemented, McClellan's energy consumption would be reduced by 30 to 40 percent, with 10 percent of that supplied by renewable energy sources. It is expected that the methodology outlined in this paper can be used as a model for other communities to develop their own energy plans.

ABSTRACT

JAPAN'S ENERGY SECURITY AND INTERNATIONAL COOPERATION

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Energy is indispensable for improving the standard of living.

The two oil crises in the past several years -- the one caused by the 1973-74 Middle East conflict and the other by the recent political upheavals in Iran -- forced Japan to realize that its economic recovery and development since World War II relied largely on overseas resources and were therefore founded on a highly unstable base. Compared with the United States, Japan is one twenty-fifth in area, while having more than half as much population. This situation can be best grasped by imagining a country smaller than California with more than half of the American people living in it. Japan is often described as an economic power second only to the United States in the free world, and that is true, but unlike the United States, Japan does not have most of the principal resources, importing nearly 90% of its energy requirements, almost 100% of its oil.

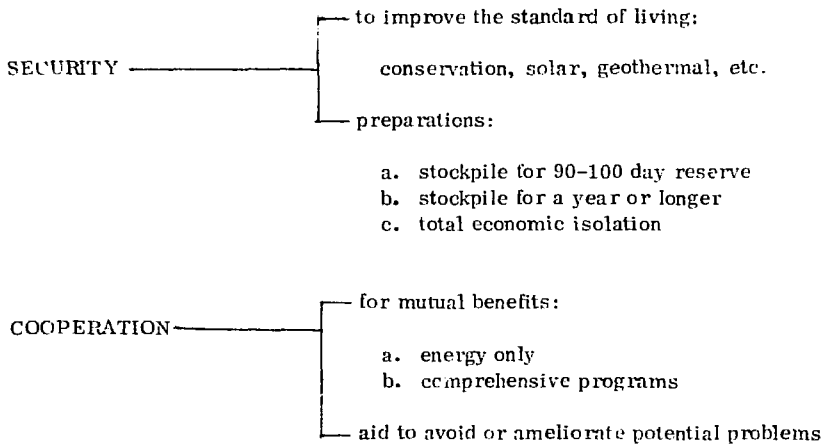
Thus, for Japan, "energy independence" is a dream that will never come true. It is, then, imperative and practical for Japan to use energy most efficiently so that dependence on overseas energy may be lessened, and to cooperate with overseas energy suppliers in mutually beneficial ways.

For Japan's energy security, preparations for supply disruptions are equally important. Ideally, such preparations should correspond to the magnitude of supply interruptions, which may last a year or longer. Fortunately, Japan still have a large number of people of the generations who experienced

destitute conditions of war and know how to survive circumstances devoid of oil. Conservation methods devised by these people are not large in scale, but could be cumulatively effective.

In this paper, I hope to touch on how Japan have managed two recent energy crises, how Japan looks at energy security and international cooperation, and some of the conservation ideas developed under emergency conditions.

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AUSTRALIA - THE UNDEFENDED SOURCE OF ENERGY

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EXTENDED ABSTRACT

THE PROBLEM (1)

Exogenous Shocks Energy and inflation are the major issues of the 1980s and beyond. "Exogenous shocks" is a new economic term. OPEC, Iran and the Soviet incursion into Afganistan were exogenous shocks. The frequency and negative impact of these shocks will increase.

ENERGY One cause of tensions between the Soviet Union and the Western World is the shortage of energy. Because there is no alternative place to go, the Soviets must soon turn to the Middle East for oil. Hence an unstable and difficult environment is about to be created. The solution for most of the Western World, including the United States, and in particular Australia, is the rebuilding of a defence capacity that has deteriorated greatly since the Vietnam War. By the 1990s oil and gas will tend to be reserved for mobile fuel and for industrial feed stocks.

Alternative Energy According to Dr. Chauncey Starr who is a distinguished United States scientist and Vice Chairman of the Electric Power Research Institute by the year 2000 twenty five percent of the Western World's energy requirements will have to come via the aggressive technological development of nuclear sources. Hydro power has been virtually fully developed to produce 11 per cent of power requirements. Assuming technical breakthroughs, 6 per cent of our power can be solar. After, allowing for 2 percent from esoteric fuel sources, coal will be the remaining major source of energy.

THE TARGET

Minerals (2) With many of the critical energy resource materials, Australia is a lucky country. Alternately, Australia is a target for both economic and military aggressive pressures. Although Australia has only 0.3 per cent of the world's population, the nation has the good fortune to contain about 25 percent of the known world uranium reserves. In addition, Australia has very significant reserves of coal, together with support minerals such as bauxite and iron ore. The addition of uranium sales to energy hungry nations will add to overseas earnings to provide capitalisation which will create further uranium-based industries in Australia.

Employment (2) Ideally, Australia's rich energy sources should be employed for the benefit of the people of the world provided that the Australian life-style is not unduly subject to interference. Emotionalism is prone to enter and perhaps cloud any discussion on uranium mining and nuclear energy.

Capitalism, Socialism or Barbarism (3) "Australian capitalism is in crisis, as it tries to adjust to the gyrations of world capitalism. Associate Professor Ted Wainwright of Sydney University believes that Australia is unlikely to adopt a form of independent socialism which could extricate it from its predicament; and there is a danger of barbarism emerging in the form of an Australian variety of neo-fascism. In the process, the nation may well begin to disintegrate, caught in the vortex between two imperialisms, American and Japanese.

AUSTRALIA'S DEFENCE

Australia has an area of about 8 M square kilometers, a coastline of 36,800 kilometres and a population of just less than 14 million people. Sixty four point five percent of the population is concentrated in major urban areas, twenty one point one percent in other urban areas with population of less than 100,000 fourteen point three percent is in rural areas while about one tenth of one per cent is migratory. Defence of the Australian Continent is limited to a permanent force of about 70,000 (including about 16,000 navy and 21,500 air force). There are about 1,000, 500 and 24,000 in the navy, airforce and army reserve forces. However, the army reserve is being increased to 30,000. Hence, the population, let alone the Defence Forces are minute when compared with Australia as a target.

CONCLUSIONS

By the year 2000, Australia's coal and uranium will make the country a significant target for economic and military aggressive countries. After economic and military aggressive countries. After examining the evidence, the paper concludes that Australia is undefended, in part to economic aggression, but more particularly to military aggression. Hence, there is a real danger that Australia's energy sources will become overtly or covertly controlled by non-Australians.

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2. Titterton E.W., (1979) Uranium, Energy Source of the Future? The Case For, Abacus, Melbourne.
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THE FUEL USE ACT: DEVELOPING A MATRIX
OF VIABLE ALTERNATE FUELS AND TECHNOLOGIES

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EXTENDED ABSTRACT

INTRODUCTION

The Powerplant and Industrial Fuel Use Act (FUA) prohibits the use of oil and natural gas in new large industrial boilers and utility powerplants. To facilitate the use of alternative fuels, the Department of Energy (DOE) intends to develop a matrix specifying viable alternate fuels, innovative technologies, mixtures and conservation measures (hereafter referred to as fuel technologies) suitable for use by large industrial and utility facilities.

FUA AUTHORITY AND PROCEDURES

In addition to the statutory prohibitions on oil and natural gas use by new facilities, existing utilities may not use natural gas after 1990. DOE also is authorized to prohibit oil and gas use in existing facilities capable of using an alternate fuel. DOE may also, in facilities capable of using mixtures of oil or natural gas and an alternate fuel, limit the amount of oil or natural gas used in the mixture.

Permanent and temporary exemptions are available for facilities not capable of using alternate fuels or mixtures (for technical or economic reasons). Facilities that receive an exemption from FUA prohibitions may be subject to Terms and Conditions that require the use of effective fuel conservation measures.

The procedures for petitioning for an exemption from the FUA prohibitions usually require the petitioner to demonstrate that it is not feasible to use some alternative to oil or natural gas, e.g., coal, coal-oil mixtures, solar, wood, low/medium BTU gas, etc. The granting of an exemption generally depends substantially upon the technical and economic assessment of these alternatives.

MATRIX OF VIABLE FUEL TECHNOLOGIES

The matrix will specify which fuel technologies are considered viable now (and in the next ten years) including the specific applicability of the technology. The matrix will be flexible--updated as technology and economics change.

There are three primary benefits of a fuel technology matrix: it will reduce regulatory uncertainty by informing potential petitioners for exemptions which alternatives they will likely have to assess; it will provide current information on fuel technology readiness and applicability which is particularly useful to smaller industries and utilities; and it will provide an additional means for fuel technology vendors to reach potential users.

PROCESS FOR ASSESSMENT OF FUEL TECHNOLOGIES

Process A Fuel Technology Review Committee (FTRC) has been established within DOE to assess the fuel technology candidates. Technical subcommittees will be established for each candidate (e.g., low/medium BTU gasification, solar, etc.). The FTRC will seek external technical and economic input and analysis from professional organizations, vendors, users, manufacturers, academia, environmental groups and others. Based on the technical and economic analysis, findings and recommendations will be prepared on the viability and applicability of each candidate. Guidelines will be published specifying the viable fuel technologies and their applicability in industrial and utility use.

Objectives of Process The objectives of the process are to establish technical criteria that provide a basis for assessing candidates; establish criteria for determining the readiness of a fuel technology; assess economic viability in the context of the FUA cost criteria; draw on external technical expertise; make a collective DOE assessment on fuel technology readiness; and maintain flexibility to respond quickly to economic and technology changes.

POTENTIAL FUEL TECHNOLOGY CANDIDATES

The initial fuel technologies likely to be subjected to systematic assessment are atmospheric fluidized bed combustion, coal-oil mixtures and low/medium BTU gasification. Other candidates likely to be assessed include solar applications,

wood/biomass, municipal wastes, black liquor, shale oil, geothermal, coal liquefaction, pollution control equipment and agricultural wastes.

ISSUES AND CONCERNS

Following are some of the issues and concerns to be addressed:

- Development and maintenance of broad private sector input into the assessment process.
- Establishment of balanced criteria for determining "readiness" so as to avoid forcing premature use of unproven fuel technologies in new applications.
- Avoidance of the discouragement of the development of fuel technologies not yet ready for inclusion in the matrix.

POLICY IMPLICATIONS OF ENERGY/DEVELOPMENT
RELATIONSHIPS

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EXTENDED ABSTRACT

This paper describes the results of quantitative analyses of the relationships between energy production and consumption on one hand and indicators of economic and social progress in Less Developed Countries (LDCs). The purpose of this analysis is to provide insight on energy-economic-social relationships that will be useful in the formulation of both energy-specific and overall development assistance policy.

The scope of our analysis is best covered by listing a series of broad questions that we attempted to answer:

- What is the relationship between commercial energy consumption and overall and sectoral economic growth for LDCs?
- What has been the impact of increases in the cost of imported energy upon the growth rates of LDCs?
- What has been the impact of increases in the cost of imported energy upon the inflation rates of LDCs?
- What has been the impact of increases in the cost of imported energy upon the balance of payments of LDCs?
- What is the role of non-commercial energy in the development process and how is this role influenced by increased consumption of commercial energy? In which sectors are non-commercial energy consumed?
- What is the relationship between energy consumption and production and indicators of social and economic progress in LDCs?

The scope of work covers all developing countries, and a data base on 86 of them was compiled for conducting this analysis. These countries were organized by type of economy (agricultural, industrial, balanced, etc.) and per capita income level, with a

dividing point of \$250 per year between high and low income LDCs. The data coverage and quality ranged from acceptable for the major economic and energy indicators to poor and partial for some social indicators. Detailed sectoral energy and economic data were available for 16 countries, and these were subjected to further analysis. Major data sources used included World Bank economic data and United Nations energy consumption and demographic data. Sectoral energy data were taken from International Energy Agency reports.

The statistical techniques of regression analysis and factor analysis were used to examine relationships between energy consumption and indicators of social and economic development. These techniques can accurately determine correlation between variables. Correlation is a measure of the degree to which variables vary together, but does not indicate causality of the relationships discovered.

Our major findings are:

- Growth rates in GDP per capita are strongly related to growth rates in investment, employment, and energy. The few countries whose GDP and energy consumption should little relationship almost all had very low incomes, below \$250 per capita per year. The size of increase in GDP per capita as energy consumption increased varied among LDCs. However, more of the factors were examined (level of GGNP, urbanization, economy, type, energy, and oil self sufficiency in oil importers, geographic region, culture) could explain the difference.
- Sectoral GDP and energy consumption also increased together in most nations studied for each of the three sectors examined: industry, transportation, and agriculture. Surprisingly, this growth is not related to the population size of the LDC; normalizing sector output and energy consumption by population actually masks the trends.
- A unit increase in energy consumption appears to have by far the greatest impact in agriculture output. The increase in agricultural productivity frequently exceeds that of both industry and transportation by a factor of 10 or more, for example, in Brazil, Egypt, India, Korea, and Mexico.
- The significance of energy to economic development in LDCs is emphasized by the deleterious effects which have resulted from the oil price rises of 1973-1974. Developing countries which depend on imported oil suffered severe repercussions:

- Real GNP per capita growth rate dropped by more than half (from 3.1 percent to 1.5 percent) after 1973. Those countries which were growing most rapidly suffered the largest declines.
- Inflation rates more than tripled (from 7.7 percent to 24.5 percent) after 1973.
- Real balance of payments deficits nearly tripled after 1973.

These effects were reversed or much reduced for oil-exporting LCD.

- Non-commercial energy (i.e., energy which is not commercially traded) is a traditional source of fuel in most LDCs. However, as total energy consumption and GDP increase over time, noncommercial energy consumption remains stagnant. Thus, noncommercial energy appears to have a limited role in economic growth. Therefore, energy assistance should be broadbased to include other than renewable energy sources. Although noncommercial energy is used primarily in subsistence living, it is also used as an industrial fuel in several LDCs.
- Noncommercial energy is a major fuel in many LDCs. Based on the data available, the role of noncommercial energy seems to decline as commercial energy consumption increases. It is, however, the major industrial fuel source in two LDCs--Columbia and Kenya.
- The relationship between the Physical Quality of Life (PQLI) and energy consumption appears to be relatively independent of the economic structure of the country or its geographical location, but appears to be affected by the culture of the country as expressed by its dominant religion. Generally, for a given PQLI, Islamic countries have higher energy consumptions and GDPs than Christian countries, and Christian countries are higher than Bhuddhist or Hindu countries. Thus, the way in which resources are used may be as important in affecting the PQLI as the absolute level of the resources.
- The analysis of quality of indicators showed that all indicators (health, cultural, economic) improved together, rather than some set increasing before the other change. Because of this fact, indices other than the Physical Quality of Life would be equally indicative of societal change. A

few countries do show exceptional patterns of development; Sri Lanka, for example, has a high quality of life associated with low economic development, and Mauritania has a low quality of life but high economic development.

Acknowledgement: The authors thank Dr. Jerome Bosken of Agency for International Development for suggesting that we undertake this analysis and then offering his support. We are deeply indebted to our colleagues Dr. Wayne R. Park and Joke Verhoeff, who performed portions of the analysis presented here and also are coauthors of the reports from which this material is excerpted.

FRESH WATER SUPPLY TO OIL PRODUCING COUNTRIES
BY MEANS OF CRUDE OIL TANKERS

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EXTENDED ABSTRACT

INTRODUCTION

Major oil producing countries on Arabian Gulf such as Kuwait, Saudi Arabia, Qatar, U.A.E. are involved in ever-lasting struggle for obtaining good water, where the water supply is mostly derived from underground brackish water, or sea water desalination, very few oasis, and even iceberg towing from Antarctic is discussed.

On the other hand, Japan importing about 250 million tons of crude oil annually from those Arabian Gulf countries, is blessed with abundant of good natural water due to heavy rain fall.

Transportation of crude oil from Arabian Gulf to Japan are being made by tankers, however return voyages of those tankers carry air, or more exactly, considerable amount of sea water as ballast of tankers. The similar scene might be observed between Arabian Gulf and North America or North Europe.

Any body can think of an idea to transport fresh water through the return voyage of oil tankers, as they very often bridge between regions of water sufficiency and regions of water deficiency like Arabian Gulf area and Japan. However at the same time such an idea was easily scrapped because of strong impression of water contamination affected by crude oil, while the present technical standard easily separates oil residue from water into very refine fresh water in fact.

Under such circumstances, please let us report about our project to propose Arabian Gulf countries to adopt it as one of practical measures to obtain good fresh water. From ourselves the project organizer's point of view, it is not innovation at all, but mere recommendation to use the existing bridges to little more extent.

The scheme might be more or less "Egg of Columbus" at present, however, in ten years time it will be more popular egg that can be easily hatched, which I can prove by mentioning the fact that majority of crude oil tankers existing at that time in the world would be equipped with segregated ballast tank up to 30 to 40 per cent of deadweight and anybody

would think that such space should not carry sea water just as balance weight from area of water sufficiency to water deficiency.

WHAT MADE THE PROJECT REALISTIC

One of the factors which made the project realistic is a provision of the Inter-Governmental Maritime Consultative Organization (IMCO) Protocol under which existing tankers shall be equipped, within a certain time schedule, with crude oil washing (COW) system, as well as segregated ballast tank (SBT) for newly built tankers, thus enabling them to transport fresh water with low degree of contamination in cargo space, with no oil contamination in SBT on their return voyage.

Another thing of encouragement to the project is rediscover of Yakushima, the island located southern part of Japanese archipelago, where annual rainfall exceeds 8,000 millimeters and its natural surrounding of high mountain and forests enables constant supply of good natural water all the year round.

Something new in the project is application of water treatment technique in fresh water utilization procedure, where raw water with little oil residue shall be treated through, for instance, air flotation, sand filtering, and activated carbon adsorption process so that purified fresh water with no oil detected, no oily odour at all, can be obtained.

TECHNICAL AND ECONOMICAL ASPECTS OF THE SCHEME

Transportation of fresh water by tanker itself is nothing new nor matter of technical innovation. However in order to realize fresh water transportation by return voyage of oil tanker, the following consideration shall be taken as substance of the scheme:

- Supply contract of fresh water shall be made on stable long term and mutual trust basis.
- Delivery term of fresh water shall be principally on ex Water Loading Point (or FOB Yakushima) basis, then ocean transportation of fresh water shall be made under the title and control of fresh water purchaser, and adequate transportation availability shall be selected from among total oil haulage.
- Sale and purchase of fresh water shall be entirely independent from deal of oil, thereby no technical (operational) nor political hindrance shall affect each other.
- Transportation of fresh water shall be made by usual tankers with no constructural modification nor special preparational operation required, so that additional cost to transport fresh water shall be minimized.

- Fresh water loading (at Yakushima) and unloading (on Arabian Gulf) facilities shall be so designed and constructed as to make those operation carried out by minimum time engagement for tankers.
- Water treatment shall be made after unloading from tankers through the water receiving and treatment plant properly prepared in accordance with water users requirement.

RECOMMENDATION AND CONCLUSION

- The scheme is proposed as supplemental or secondary measures to the current water obtaining such as underground brackish water and sea water desalination in Middle East Countries.
- Partial use of natural water by proposed scheme would make water quality control easy and practical in total water acquirement of the area.
- Favourable impact on enviromental and ecological situation against problem caused by piling up of salt or thicker brine seen in the area where evaporation exceeds rainfall, as well as time to time saving of underground water resources, the preservation of which shall be considered as most important and urgent matter.
- The proposed scheme, to our wish, shall be evaluated from energy saving point of view, while energy value of water in itself is zero, huge energy is used in current water production method, as well as in relation to increasing value of development of solar energy utilization system, in which use of good water is essential and as is very important in the area where beautiful sun is always available.
- It is our wish that our project will lead and encourage the similar project in the world with the effect to contribute world energy situation.

ERRATA

The last paragraph of "Solar-Powered, Stratospheric, Manned Station", written by E.C. Okress and R.K. Soberman, should read:

At operational altitudes the aerodynamic pressure is extremely low, due to the low density and pressure found above the troposphere. The drag force on a normally directed projected area* of a 1-mile diameter STARS aerostat in a stratospheric wind of 50 mi/hr is a relatively tolerable 1908 metric tons. It can be shown that in terms of power this amounts to 2.089×10^8 watts, in contrast to the solar power available on the STARS aerostat of 1.9×10^9 watts. Hence, navigation and hovering of the STARS aerostat, even in 50 mi/hr stratospheric winds at 30-km altitude, is well within its compressed air and/or suppressed electric discharge thrust engine and power supply capabilities.

*A disk is utilized in contrast to an icosahedron structure to avoid Reynolds number, etc., complications and to emphasize such an adverse target to the wind.