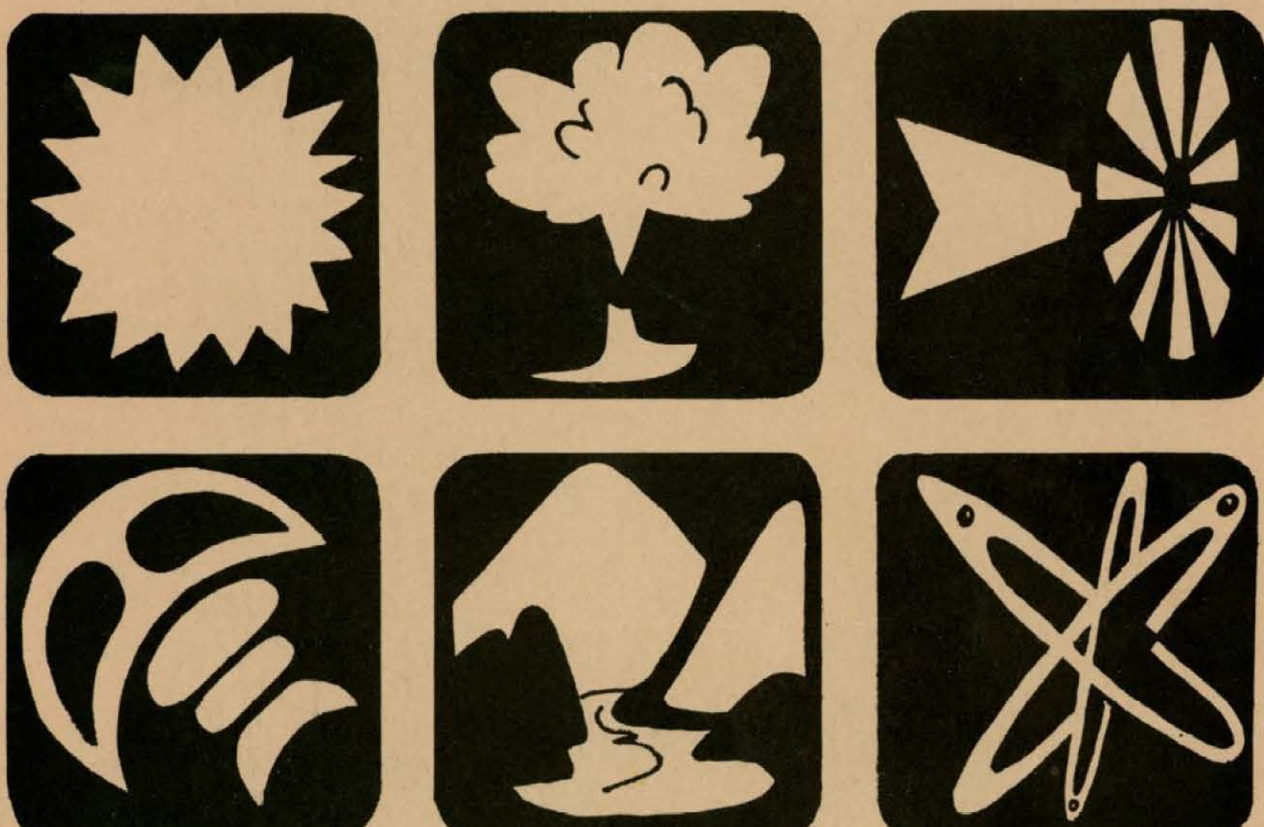
Miscellaneous Paper 18

Proceedings Of The Citizens' Forum On Potential Future Energy Sources



STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
R. E. CORCORAN, STATE GEOLOGIST

Miscellaneous Paper 18

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
1069 State Office Building, Portland, Oregon 97201

Miscellaneous Paper 18

PROCEEDINGS OF THE CITIZENS' FORUM ON POTENTIAL FUTURE ENERGY SOURCES

Smith Memorial Center
Portland State University, Portland, Oregon
January 17, 1974

Sponsored by:
Oregon Department of Geology and Mineral Industries
Portland State University, College of Science

Arrangements Committee:
Dr. Karl Dittmer, Dean, College of Science, Portland State University
Dr. Erwin F. Lange, Associate Dean, College of Science, Portland State University
Raymond E. Corcoran, State Geologist, Oregon Department of Geology and Mineral Industries

1975

STATE OF OREGON
1859

TOM McCALL
GOVERNOR

OFFICE OF THE GOVERNOR
STATE CAPITOL
SALEM 97310

July 11, 1974

Mr. R. E. Corcoran
State Geologist
State Office Building
1400 S. W. Fifth Avenue
Portland, Oregon 97201

Dear Andy:

My commendations and appreciation to you, your Board and staff, and all who took part in your conference on "Potential Future Energy Sources" staged in Portland, January 17, 1974. Reports to me uniformly reflect the high quality of the presentations and discussion, and the significant contribution that was made to our understanding of energy, and the energy crisis facing our state and nation.

Your conference was the third in an important series of Citizen Forums. The first, staged in Eugene, brought over two hundred industrial leaders together discussing measures which could be taken to keep Oregon's economy moving and to minimize disruption because of faltering supplies of essential energy. The second, staged in Corvallis under the direction of Oregon State University, emphasizing the importance of citizen action in participating in energy conservation, and leading to a better understanding of the reasons for the energy crunch. Your splendid program extended our discussions to the future of energy sources. It was much appreciated, and I am delighted to know that your Department is publishing the papers delivered at the forum.

Best wishes.

Sincerely,

Tom

Governor

TM:cm

PROCEEDINGS OF THE CITIZENS' FORUM

ON

POTENTIAL FUTURE ENERGY SOURCES

INTRODUCTION

Energy is the sustenance of our civilization. It is the basic driving force in the maintenance of our well-being - nutrition, health, shelter, transportation, communication, recreation, agriculture, and industry.

Most of the energy used by man comes from fossil fuels and is used in the form of natural gas, gasoline and diesel fuel, coal, and electricity. The conventional sources of energy - petroleum, natural gas, coal, and hydroelectric - are in finite supply and depletion seems imminent. This is especially true of those forms of energy which have the properties for specific uses, such as gasol e for the internal combustion engine of the automobile. Only when it became difficult to get all the gasoline we wanted did we begin to think in terms of a limited supply.

"We've gotten the idea that energy in abundance would be forever at our fingertips," Oregon Governor Tom McCall said in his statement on Conservation of Energy for Consumers, August 22, 1973, after the Declaration of an Energy Emergency, by Executive Order on August 21, 1973. The energy crisis in Oregon resulted from an untimely melt of the winter snowpack and a lack of rain which reduced the hydroelectric power dams to dangerously low levels. This was compounded by the limited supplies of gasoline.

Governor Tom McCall proclaimed a series of public forums throughout the State in order to acquaint its citizens with various aspects of the energy crisis as it applied to Oregon. The Oregon Department of Geology and Mineral Industries and the College of Science of Portland State University responded by conducting this Citizens' Forum on Potential Future Energy Sources on January 17, 1974.

Nuclear energy is the most advanced of the new energy sources and was not discussed during the forum. The potential future of wind power, solar power, geothermal power, conversion of oil shale, and coal gasification and liquefaction was presented by experts who have special knowledge about these sources of energy not now being utilized in this country to a significant degree. Their data and its interpretation, as presented in this volume, should provide some of the information necessary to understand the advantages and limitations of some of the alternate sources of energy. It is hoped these papers will help to generate incentives to develop future energy sources.

Karl Dittmer
Dean of the College of Science
Portland State University

THE ENERGY PROBLEM

Roy Foleen

Deputy Administrator, Bonneville Power Administration
Portland, Oregon

The biggest problem the utilities have today is one of credibility. We have often been asked, "Is there really an energy problem?" The answer is "Yes, there is an energy problem, and yes, there is a solution to it."

I would first like to direct your attention to the Pacific Northwest power outlook. In 1974 the region used, on its peak day, something in the order of 21,000 megawatts of electric power. Twenty-one thousand megawatts is equivalent to about 10½ Grand Coulee dams or 42 Bonneville dams. By 1994 the peak use is expected to grow to over 60,000 megawatts. Again, in terms of Grand Coulee dams, this would require more than 30 Grand Coulee dams. Yet, this represents less than a 6 percent annual load growth within the Pacific Northwest. I might add that the national average load growth is approaching 7 percent per year, so our future prediction at this time is that the Northwest load growth will be less than the national average.

This illustrates one of our biggest problems--that of making load estimates upon which to base our planning of future generation and transmission. The reason it is so difficult is that we are now experiencing a dramatic change in load estimates and in the balance of usage among the various energy forms.

The electric heating increment we forecast within our loads is undergoing tremendous expansion. One utility reported to us that, whereas normally 55 percent of new building starts in its service area are electrically heated, during the past year this has jumped to 85 percent. As people see difficulties in getting oil and natural gas, the conversions to electric heat will multiply. We will see a great deal of such conversion in the food processing industry--using electricity to heat boilers instead of using natural gas or oil. Manufacturers are interested in a reliable energy supply and are willing, in some instances, to pay a higher price for it. Even our most recent load estimates have become outdated and overly conservative. For instance, we know that for 1983 something in the order of 300 to 500 megawatts is not included in the latest load estimates.

Also, the region is very termperature sensitive, which adds to the difficulty in load estimating. For example, for every 1°F drop in temperature in the wintertime, we require an increase of approximately 100,000 kilowatts of generation in the region. This means that if we have a 5° drop, there is a load increase of about the output of a Bonneville Dam. This temperature factor is, therefore, very important in the kind of assumptions we make in terms of our load estimating. I might add that the regional load estimates have been very accurate in the past, within a 3 percent range of error. As we gain experience with new factors being cranked into the energy equation, we hope to be just as accurate.

Turning now to the Northwest hydro situation, I might point out that the power generated in the Northwest is 85 percent hydro. The usage--the number of kilowatt-hours used per customer in the Northwest--is twice the national average. On the other hand, the total energy each citizen uses in the Northwest is about the same as the national average. This indicates that the Northwest citizen makes a much greater use of electricity than those living in other parts of the United States. In a sense, we have a built-in conservation program resulting from this action--by using hydro power to serve our loads we do not burn nearly so much oil, natural gas, and coal, the first two of which are in such short supply. By tapping our Columbia River and using that tremendous resource, we are provided with a renewable energy resource. While the Northwest is 85 percent hydro, the opposite is true in the Southwest. Eighty-five percent of its load is served by thermal generation such as oil, coal, and natural gas. Because of the high price of these fuels, we see a great tendency for surplus hydro power to flow from the Northwest to the Southwest to displace that high-cost fossil fuel.

Resource planning is a very important element in developing future energy strategy. First, of course, we must make our load estimates. Then, we must determine what resources are going to be built to meet those loads. During the period 1971 to 1986, based on our load estimates, the Northwest will need to construct 31,000 megawatts of hydro power and thermal power generation. I will try to put that into perspective. The Trojan nuclear plant, about 30 miles northwest of Portland, will have about 1,100 megawatts capacity. We are talking about a total of 31,000 megawatts of hydro and thermal generation. Of that 31,000, roughly 11,000 megawatts will be nuclear power, 6,000 megawatts of fossil-fired and 14,000 megawatts of hydro.

The biggest problem in resource planning is lead times. As a matter of fact, one of the main reasons why the country has difficulty in meeting its electric loads is that the utilities have not allowed sufficient lead times in constructing plants. It is not necessarily the fault of the utilities, but the lead times have lengthened tremendously in the past few years. Six years ago we figured on 6 to 7 years to build a nuclear plant. Now we talk about 10 to 12 years. Because of that, utilities find themselves in a very precarious situation. Sometimes they think a plant will be in service at a particular time, and when it is not, they have to readjust their operation schedules. Construction slippage is a way of life these days. Statistics made available to us less than a year ago indicated that the average slippage time for a thermal plant was 14 months. A year earlier the average plant came into service only 9 months behind schedule. In 1 year's time the average slippage increased by 5 months. We also have tremendous hydro-plant slippages-- in particular, the Third Powerhouse at Grand Coulee Dam. Based upon forecasts made in 1969, we are 3,000 megawatts behind schedule in some upcoming years.

The President announced recently the national goal of energy self-sufficiency. But we will never be able to obtain energy self-sufficiency until we learn to use our resources correctly. In using them correctly, we must invoke true energy conservation. When I refer to using resources correctly, let me give you an indication of what I mean. At the present time, 4 percent of the U. S. energy source is in the form of oil and natural gas. Yet that 4 percent meets 75 percent of the United States energy needs at the present time. That sort of priority has to change. We should put more emphasis on using electricity generated by uranium or coal to do many things that oil and gas now do. And we should husband oil and gas for those things that electricity cannot do. I believe this sort of allocation is beginning to take place. Estimates we've seen indicate that, whereas in 1970 electricity supplied 9 percent of the total U. S. energy needs, by 1990 it will serve 15 percent of these needs. So there is some effort in that direction, but this sort of priority-setting needs more national direction.

We need a great deal of effort in research and development in the end use of energy--for example, the heat pump is the most efficient way to heat and cool one's house. We need a great deal of research and testing to reduce the cost and produce more efficient heat pumps for wide-scale use. Electrified transportation is a tremendous way of saving on oil. We need mass transportation, obviously; and the electrified car has a tremendous potential for the short-haul, local transportation market. For example, studies indicate that, from a total energy standpoint, the electric car is $2\frac{1}{2}$ times more efficient than a gasoline-powered car.

With these innovations in mind, we will need more electricity, not less. The Northwest is a good example of this--by using more electricity, double the national per capita average, we now save tremendous quantities of oil and natural gas. Obviously, power generation needs by the year 2000 will be substantially increased if we make these corrections. Some load estimators indicate that we will need 50 percent more electricity by the year 2000 to make such needed changes in our energy-use pattern. But, as I stated earlier, we can generate electricity with non-depletable resources--those that are in abundant supply like uranium, by using the atom, or by coal-fired generation and coal gasification. There are other types of electric generation that have to be investigated.

We need tremendous research and development efforts in the nuclear field, especially in the breeder reactor and the fusion plant that could be the ultimate source of energy for the United States and the world. We need research and development efforts in the gasification and liquefaction of coal, and in how to eliminate air pollution so that we can use coal more efficiently and with minimum effect upon the environment. We need extensive research in oil shale, tidal power, geothermal, wind power, solar power, fuel cells-- the latter to increase the efficiency of our generating resources. Unknown to many people, 50 percent of our energy is wasted--of the total energy consumed, only 50 percent is productive. We need research and development in energy efficiencies. But what this country needs most in relation to energy generation conversion and transmission is a "can-do" attitude.

In summary, let me say that we need to conserve our depletable resources. That is, we need to conserve as best we can our oil and our natural gas. To do this, we need to switch to better and more efficient electrical uses and let electricity substitute for oil and natural gas. We obviously need more electricity, not less electricity, and that requires greater electrical generation. So we need foster construction of electrical resources for generation. I'm talking about coal plants, nuclear plants, and greater research and development in new generating sources such as those itemized earlier. We will need more forums, such as this one, to keep the general public informed and involved in this very important matter.

WIND-POWER POTENTIAL IN THE PACIFIC NORTHWEST*

E. Wendell Hewson

Chairman, Atmospheric Science
Oregon State University, Corvallis, Oregon

Introduction

Wind has been used as a source of energy from earliest times. The first windmills date from many centuries B. C. and were employed in Persia and China. These early windmills rotated on a vertical axis, some types using sails rather than curved blades. After a long period of time windmills appeared in Europe and later in North America. These early windmills pumped water or ground grain; the use of such machines for generating electricity is a relatively modern development.

Power in the Wind: Total and Usable

The winds represent the energy output of the great atmospheric heat engine. The fuel is short-wave radiation from the sun and, as in any heat engine, there is rejected heat which is lost to space by means of long-wave radiation emitted by the earth and its atmosphere. The winds (and ocean currents) are the work done by the engine and may be thought of as its flywheel. The windmill, or aerogenerator, merely taps some of the power generated by this great atmospheric heat engine.

The power in the winds is vast. It has been estimated that the total energy of the atmosphere is about 10^{14} megawatts (mw) (Putnam, 1948). If we assume that one ten-millionth of this amount is available to man, then there are 10^7 mw of usable power in the winds. This is equivalent to the output of 10,000 typical fossil-fueled or nuclear power plants of 1,000 mw each. By way of contrast, it has been estimated that the water-power potential of the whole earth is equivalent to the output of 500 such power plants (Putnam, 1948). On this basis, there is 20 times more potential for wind power than for waterpower.

Since the power generated by the wind is proportional to the cube of the wind speed, it is important to locate areas of persistent high wind. Thus, for example, a 10-meter per second (22 miles per hour) wind will produce eight times as much power as a 5 m/sec (11 mph) wind.

Research on the wind-power potential of Oregon and neighboring areas was commenced in 1971 by Oregon State University under the sponsorship of the four Oregon P.U.D.'s and has continued since that time under the same sponsorship (Hewson and others, 1973). The primary thrust of the research has been to study various possible wind-power sites, especially those at or near the Oregon coastline and in the Columbia River Valley. These studies have involved the detailed analysis of existing wind records and the establishment of new wind-measuring stations. At the same time, the wind tunnel at Oregon State University has been enlarged and improved to permit model studies of air-flow patterns around terrain features. If a comparison of model and actual air-flow patterns over and near pronounced terrain features shows satisfactory agreement, then the location of desirable wind-power sites will be greatly facilitated and expedited. Other project uses of the wind tunnel will be described later in this article.

Past Experience in Electrical Power Generation by the Wind

During the past 50 years or so, considerable experience has been gained in various countries of the world in the generation of electrical power by large wind turbines rated from 100 to 1,250 kilowatts (kw) (Golding, 1955; Hütter, 1973; Putnam, 1948). A number of these units are described briefly below.

* Research sponsored by the four Oregon P. U. D.'s: Central Lincoln, Tillamook, Clatskanie, and Northern Wasco County.

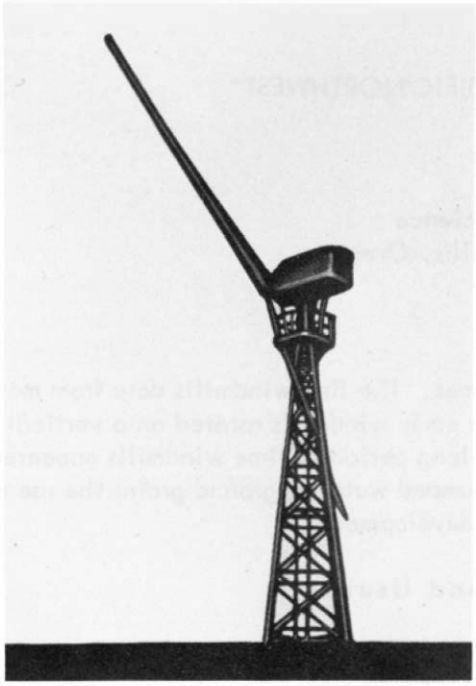


Figure 1. The Darrieus aerogenerator built at Bourget, France in 1929.

Figure 2. Aerogenerator of Russian design built at Yalta near the Black Sea in 1931.

Figure 3. The Smith-Putnam aerogenerator built near Rutland, Vermont during World War II.

Figure 4. Sketch of experimental wind turbine to be constructed at Sandusky, Ohio.

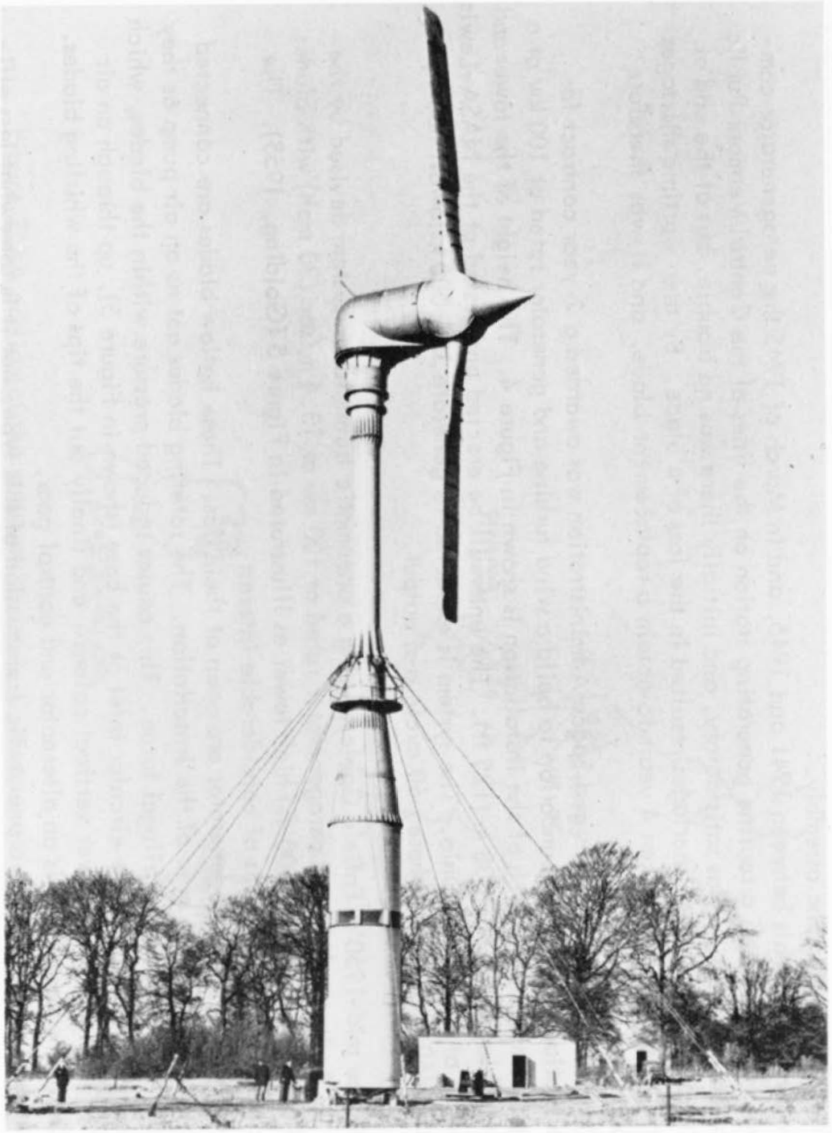


Figure 5. The Enfield-Andreau aerogenerator built in the early 1950's in Great Britain.

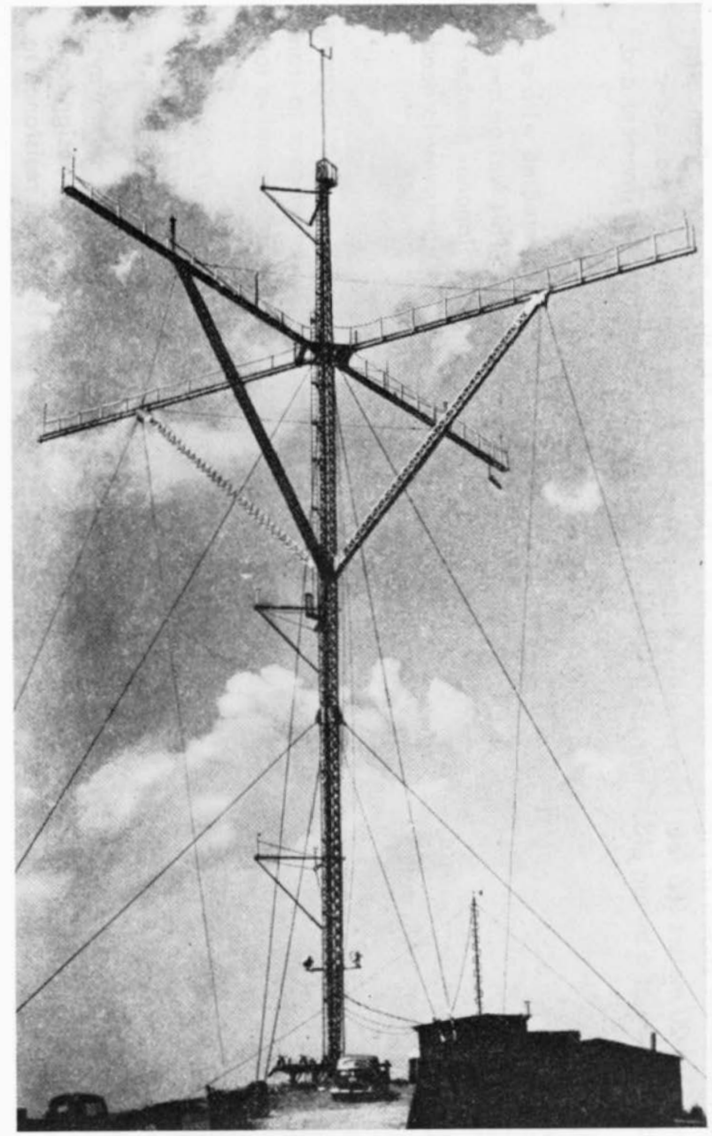


Figure 6. The meteorological tower and instruments at the site of the Smith-Putnam aerogenerator near Rutland, Vermont.

France. The aerogenerator shown in Figure 1 was designed by Darrieus and built at Bourget, France in 1929. The tower was 20 meters (66 feet) high and the blades 20 m (66 ft) in diameter. It was a d-c generator rated at 15 kw at 6 m/sec (13.4 mph). It has been described as a design of "refinement and elegance."

Russia. Two years later, in 1931, at Yalta near the Black Sea a much larger unit was erected with a tower 23 m (75 ft) high and blades 30.5 m (100 ft) in diameter as shown in Figure 2. This was an a-c unit rated at 100 kw at 11 m/sec (24.6 mph). The thrust of the wind is taken by the diagonal member whose base moves on a circular rail system as the aerogenerator rotates about the central tower to head into the wind. The phrase "bold and practical" has been applied to this aerogenerator.

Germany. In 1920 a wind turbine designed by Kumme and consisting of six blades was built in Germany. It called for a generator on the ground and a long vertical flexible shaft topped by a bevel gear to transmit torque to the ground. It was found, however, that with this arrangement it was more expensive to have the generator at the ground than aloft.

In 1933, Honnef of Berlin proposed a design for five wind turbines, each nearly 40 m (250 ft) in diameter supported on a single large tower 305 m (1,000 ft) or more in height. This unit, rated by the inventor at 50,000 kw, had a number of novel features but was never built.

More recently, relatively large aerogenerators using fiberglass blades fabricated in a novel way have been designed by U. Hütter of the University of Stuttgart (Hütter, 1973). Units of his design have been constructed and operated and have proven to have good operating characteristics and resistance to fatigue.

United States. The largest wind turbine which has been built, an a-c generator rated at 1,250 kw at 13.4 m/sec (30 mph), was constructed on high ground near Rutland, Vermont during World War II (Putnam, 1948). This aerogenerator, illustrated in Figure 3, consisted of a two-bladed rotor 53 m (175 ft) in diameter mounted on a 33-m (110-ft) tower. The generator was located upwind from the tower and the blades downwind from it; the whole unit was kept headed into the wind by a wind vane aloft which actuated suitable servomechanisms which rotated the assembly.

Tests were run at intervals between 1941 and 1945, and in March of 1945 the aerogenerator commenced continuous cooperation as a routine generating station on the lines of the Central Vermont Public Service Corporation. Operation was satisfactory, and initially there was no trouble, but at the end of 23 days a defect caused by wartime shortages resulted in the loss of a blade. By then wartime shortages were so severe that it would have taken 4 years to obtain a replacement blade, and it was therefore decided to abandon the undertaking.

In 1974 the National Aeronautics and Space Administration was awarded a 2-year contract for $865,000 by the National Science Foundation to build a wind turbine and generator rated at 100 kw at a speed of 8 m/sec (19 mph). A sketch of the installation is shown in Figure 4. The height of the towerand the diameter of the blades are each 38 m (125 ft). The unit will be erected and tested at the NASA-Lewis Plum Brook test area at Sandusky, Ohio. The system is expected to generate 180,000 kilowatt hours per year in the form of 460 volt, three phase, 60 cycle a-c output.

Great Britain. In the mid-1950's, Enfield Cables, using a pneumatic transmission system devised by the French engineer J. Andreau, built an aerogenerator rated at 100 kw at 13.4 m/sec (30 mph) with blades 24 m (80 ft) in diameter on a 30-m (100-ft) high tower as illustrated in Figure 5 (Golding, 1955). The novel pneumatic transmission system is of considerable interest.

The hollow blades of the aerogenerator are open at their tips. These hollow blades are connected to an air column extending to the base of the installation. The rotating blades act as an air pump as they throw air from their open tips by centrifugal force. This causes reduced pressure within the blades, which draws air into the machine through the circular inlet at the base (shown in Figure 5), up through an air turbine just above, then up the narrower vertical column, and finally out the tips of the whirling blades. Below the air inlet in the base there is an alternator and control gear.

There are several advantages to a pneumatic transmission of this type, but it is somewhat less efficient than more conventional devices. The Enfield-Andreau unit operated successfully for a number of years in Algeria.

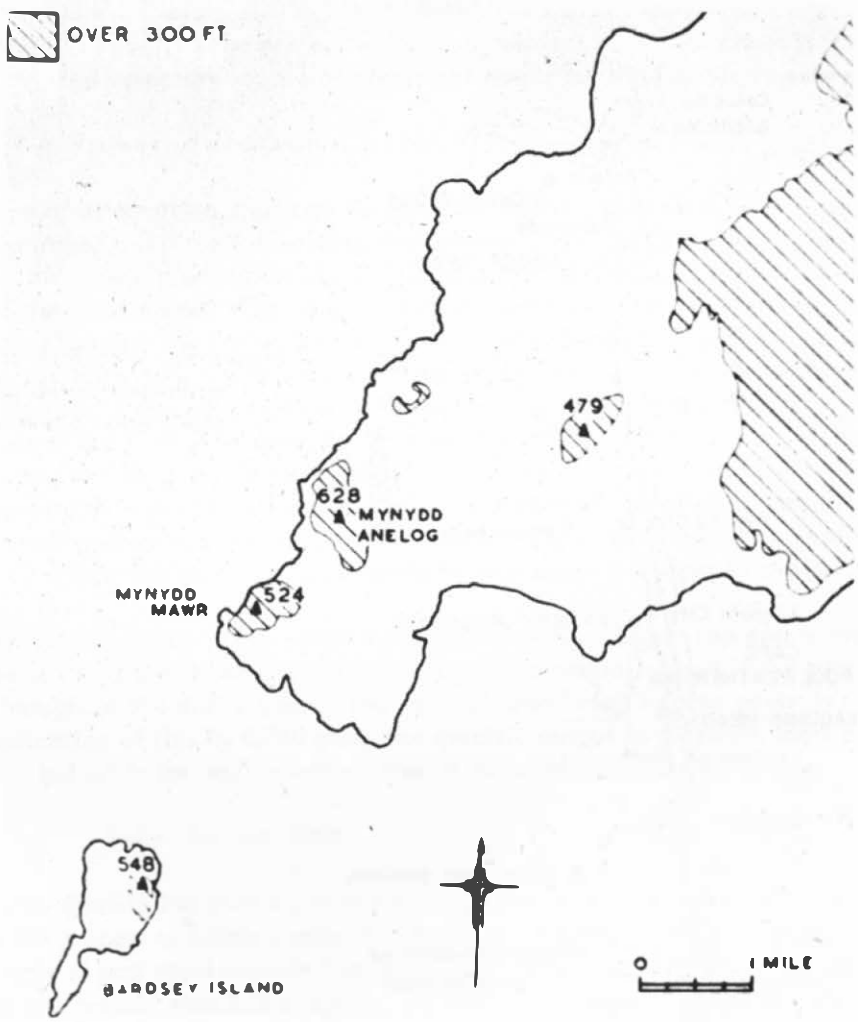


Figure 7. A portion of the coast of Wales in Coernarvonshire, which proved to have potential as a wind-power site.

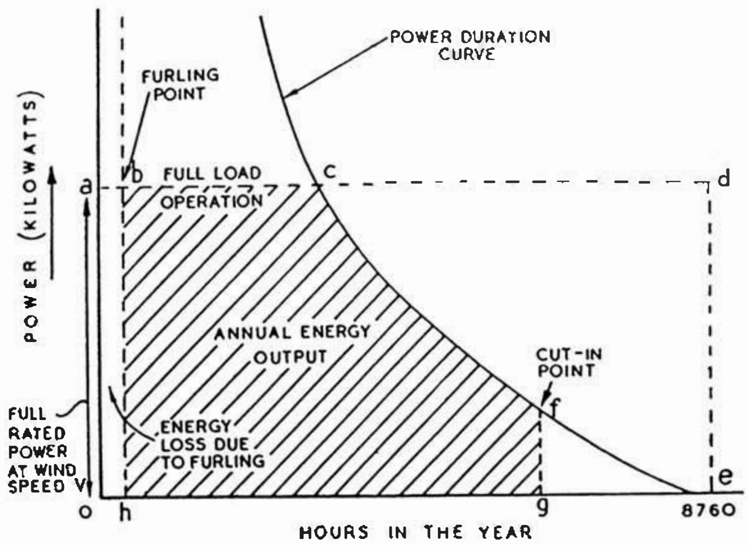


Figure 8. The power-duration curve.

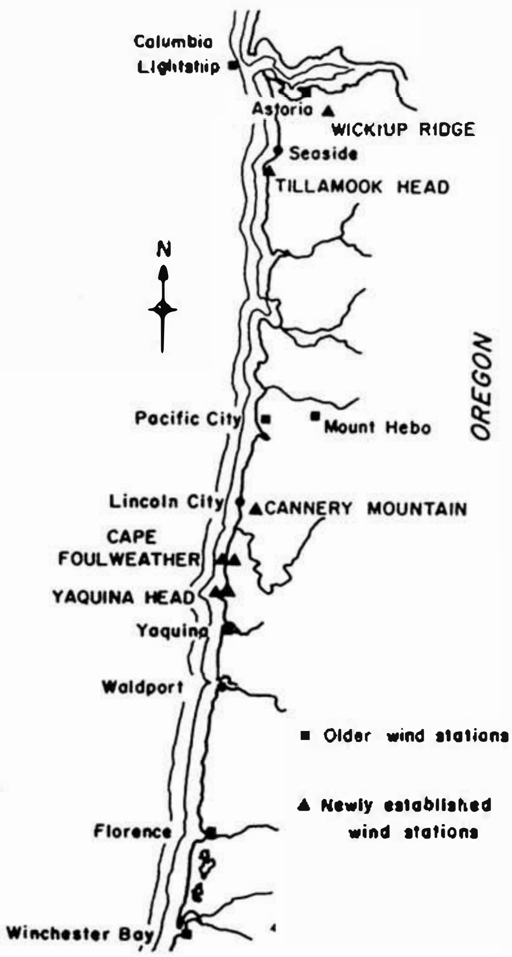


Figure 9. Locations of previously existing and newly established wind stations along and near the Oregon Coast.

Wind-power Surveys

Substantial wind-power surveys have been conducted in the United States, France, and Great Britain.

Between 1940 and 1945, as part of the program for the construction of the 1,250-kw aerogenerator in Vermont described earlier, 20 sites in the Green Mountains of Vermont and nearby areas were selected and instrumented with wind-measuring equipment (Putnam, 1948). Some of the sites were studied for no more than 6 months, but this period turned out to be too short. It is clear from the Vermont experience that, in rough terrain especially, the wind measurements must be taken with great care.

At the actual site chosen, a 56-m (185-ft) steel tower, named The Christmas Tree because of its branching arms, shown in Figure 6, was fitted with anemometers at various levels. This tower with its horizontal members permitted rather complete measurements of the wind field to which the big aerogenerator would be exposed.

In France, commencing in 1946, some 150 instruments designed to give the energy in the wind directly in kilowatt hours were installed on sites located in all parts of the country. The program was under the direction of a Committee on Wind Energy and was assisted in certain studies of the variation of wind speed with height by the Research Department of Electricité de France (Golding, 1955).

The Electrical Research Association in Great Britain, at about the same time, commenced a large wind survey of various sites (Golding, 1955). Most of the better sites were located on the windier western coasts of Wales, Scotland, and Ireland. Figure 7 shows a portion of the coast of Wales, in Caernarvonshire, which proved to be an attractive site. Certain similarities between the coastal terrain of western Wales and Scotland and that of western Oregon led the present writer to consider the possibility that the wind might prove to be an economical supplementary source of electrical power for the Pacific Northwest.

The Power-duration Curve

The single most valuable piece of information that can be obtained about a potential wind-power site is its power-duration curve, illustrated in Figure 8 (Golding and Stodhart, 1949, 1952). The horizontal axis gives the number of hours in the year, the total being 8,760, and the vertical axis is wind power, which is proportional to the cube of the wind speed. The power-duration curve shown thus gives the number of hours per year that the power output reaches the indicated values which are obtained in part by cubing the wind speed. This curve is for a site with very few calm periods during the year. In the interval ge, the wind is too light to produce a significant amount of power. At the wind speed corresponding to g, say 3 m/sec (7 mph), appreciable power is being generated; fg is called the "cut-in point." With higher wind speeds the power output is greater and at c the aerogenerator is operating at its rated capacity. At greater wind speeds the output is generally held constant at this value for full load operation by adjusting the pitch of the blades or by some other appropriate method. At some much higher wind speed, b, called the "furling point," perhaps about 27 m/sec (60 mph), it is advisable to shut down the plant to avoid damage.

In this diagram (Figure 8), the hatched area bcfgh under the power-duration curve represents the annual output of energy to the same scale as the rectangle adeo represents the annual output if the plant were running at full-rated power throughout the entire year. The ratio of area bcfgh to area adeo is the annual plant load factor and multiplication of this by 8,760 gives the specific output in kilowatt hours per year per kilowatt. Thus the specific output is the equivalent number of hours of full-load operation.

Site Selection

A number of possible sites in the Pacific Northwest, with particular emphasis on coastal areas and the Columbia River Valley, are in the process of being evaluated (Hewson and others, 1973; Hewson, 1973). This evaluation is based on an analysis of past wind records from many sources and of wind records from stations established in the course of the present research program. It will also make increasing use of a wind tunnel which has recently been enlarged and remodeled to permit research of this type.

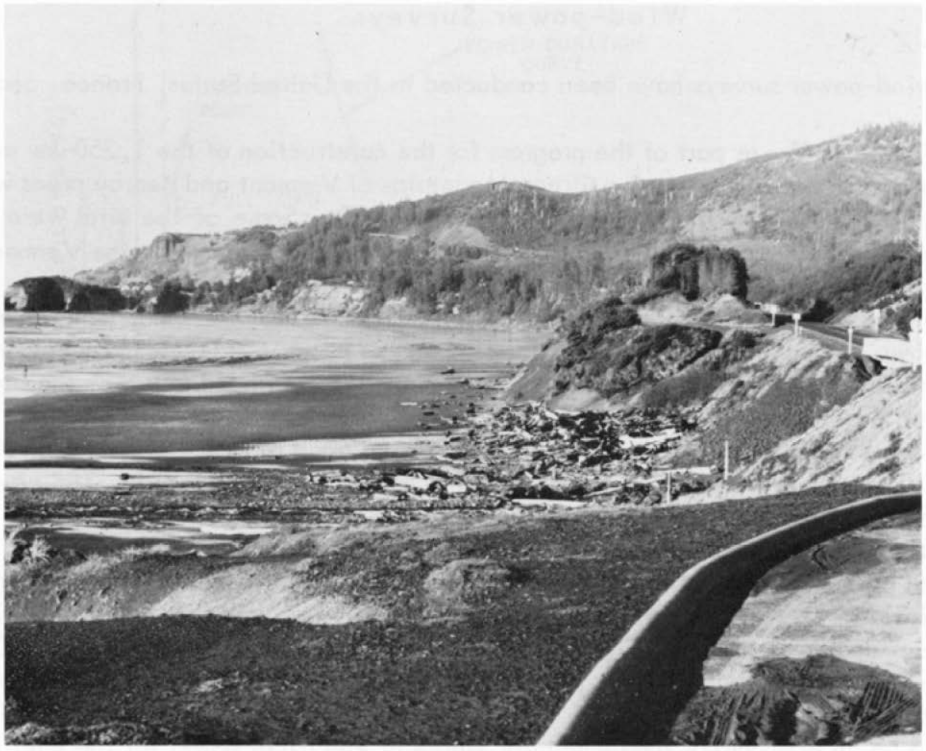


Figure 10. Cape Foulweather on which two wind stations were established.

Figure 11. Anemometer location on Tillamook Head.

A different and more recent set of power duration curves is presented in Figure 17. The power in the winds at the Columbia Lightship is surprisingly greater for 1973 than it was for the longer term (annual) average. The reasons for this large difference are being explored. The average annual power in the winds at Crown Point, a promontory located at the western end of the Columbia River Gorge about 8 km (5 mi) east of Corbett is also large. The degree of turbulence in the wind at Crown Point is not known, but it may be too high for conventional aerogenerators. The annual average for the Columbia Lightship is presented for comparison. The lowest curve is for the lower wind station, called the Lookout, on Cape Foulweather, which is shown in Figure 10.

Energy Storage and Site Location. If the wind is to be thought of as a source of firm power rather than as a supplementary source, then some method of storing the power generated by the wind must be devised. Pump storage is often suggested. This involves using the wind energy to pump water into a higher reservoir from which hydropower is developed as the water falls. Such a solution involves additional disturbance of the environment to create a reservoir if none is already available and additional cost as well. Another possible method of storage which would not affect the environment is the use of a modern flywheel, a device which has been raised to a surprisingly high level of efficiency.

At the present time it is recommended that power not be stored but fed directly into the grids as it is developed. At such times, substantial amounts of coal, oil, natural gas, or reservoir water would be conserved by the use of the wind as a supplementary source of power.

Wind-Tunnel Modeling for Site Selection. Although 30 years ago wind-tunnel modeling was attempted as an aid in site selection with limited success, it is believed that modern wind tunnels and modern methods of using them have substantially greater prospects of success. One of Oregon State University's wind tunnels was therefore expanded and improved for this and other purposes. It now has a cross section 1.5 m (5 ft) by 1.2 m (4 ft), with a working section 9 m (30 ft) long, and an adjustable ceiling. The tunnel produces winds up to 27 m/sec (60 mph). Figure 18 is a photograph of the wind tunnel after its working section had been lengthened greatly and other improvements incorporated.

A model of Yaquina Head has been constructed for wind-tunnel tests. As Figure 9 indicates, two wind stations have been established on Yaquina Head to permit actual wind measurements to be made. A comparison of the winds measured on Yaquina Head with those measured in the wind tunnel around the model of Yaquina Head will provide important information on the applicability of the method. If model tests in the wind tunnel can be used in site selection instead of lengthy series of wind measurements, it will permit substantial savings in time and money.

Terrain Modification in Relation to Site Selection. It may be that terrain modification will become an important factor in certain site selections (Hewson and others, 1973; Hewson, 1973). It is well known that a fluid entering a constriction in a channel experiences an acceleration. The higher winds of the Columbia River Gorge are an example of the operation in nature of this principle. It is possible that minor terrain modifications of a site might increase substantially the wind-power potential of the site in this way.

Figure 19 shows a hypothetical example of how such terrain modification might increase winds. Point C is part of a saddleback system in which B and D are high ground. Excavation in the area, indicated by minuses, and fill, represented by pluses, may enhance the existing venturi effect caused by the saddleback. Because of the dependence of wind power on the cube of the wind speed, even a modest 10 percent increase in wind speed due to an augmented venturi effect resulting from terrain modification might well prove to be worthwhile.

The effectiveness of various types of terrain modification will be tested, using models in the wind tunnel.

Aerogenerator Design

Wind turbines of various types, both conventional units and novel designs, will be studied using models in the wind tunnel and perhaps small-scale models in the actual atmosphere. A number of designs are being considered. One such aerogenerator is described briefly below.

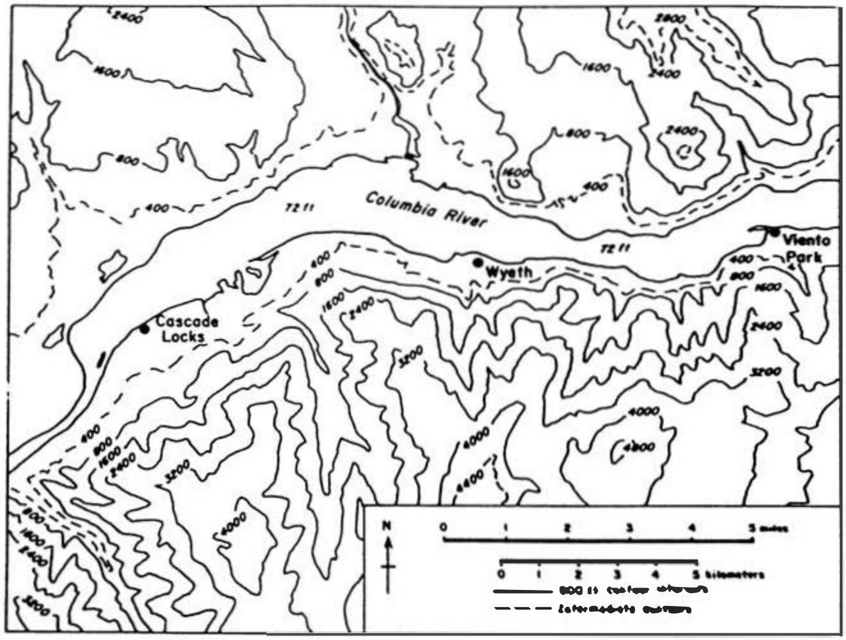


Figure 12. Contour map of the Columbia River Gorge showing locations of stations at which pilot balloon observations were made: Cascade Locks, Wyeth, and Viento Park.

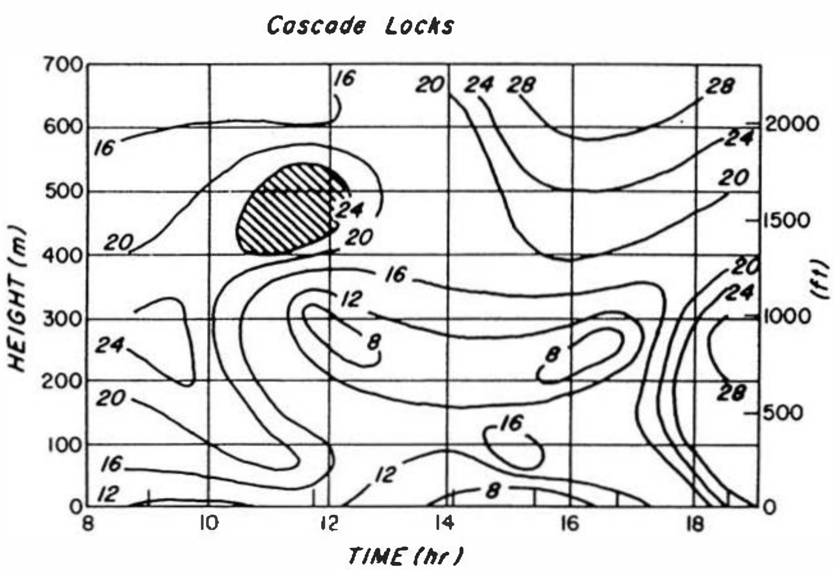


Figure 13. Isovents of equal up-valley wind speeds in knots on September 5. 1972 at Cascade Locks, Oregon. The hatched area indicates extreme gustiness or turbulence.

Evaluation of Wind Records. A substantial number of wind-measuring stations are or have been maintained along the Oregon Coast. The locations of these and of the wind stations especially established by the present project are shown in Figure 9. A number of the new stations could not be located in the best possible positions because of the lack of adequate access and the difficulty in servicing the instruments when heavy snowfalls occurred in the Coast Range. Figure 10 is a photograph of Cape Foulweather on which two stations were established, one--to the left in the photograph--at 150 m (about 500 ft) above mean sea level and the other near the peak to the right at about 300 m (about 1,000 ft) above msl. The lower station, situated near a small gift shop called "The Outlook," proved to have higher winds than the upper station. A power duration curve for the lower station is presented later, along with curves for other stations.

A station was operated on Tillamook Head for several months but vandalism and servicing the equipment proved to be problems. The anemometer, at a height of about 370 m (over 1,200 ft), is shown in Figure 11, with the town of Seaside in the distance. The recorder was first installed on the pole at a height of about 3 m (10 ft). At the end of the first week of operation the installation was inspected, and it was discovered that during that time the recorder had been stolen. The recorder was then moved to 6 m (20 ft), the position shown in Figure 11, and serviced by using an extension ladder carried on the truck for that purpose. This arrangement succeeded in preventing further vandalism.

The winds in the Columbia River Gorge (Figure 12) have been analyzed less intensively. The gorge winds are known to be relatively strong but are also reported to be very gusty at times. Extreme gustiness, if it occurred, would place a severe strain on a conventional aerogenerator. In order to discover whether gustiness does occur, pilot balloon observations, initially single theodolite measurements, were made for a selected period. Figure 13 shows lines of equal upper-wind-speed component, expressed in knots, along the center line of the Gorge near Cascade Locks during daylight hours on September 5, 1972. Such lines are sometimes called isovents. Extreme turbulence appears in such an isovent chart as extreme variations of wind speed or wind direction or of both. The hatched area indicates extreme gustiness or turbulence. The occurrence of such gustiness has been confirmed by later, more accurate, pilot balloon observations using the more reliable two-theodolite technique.

Comparison of Wind Speeds at Various Sites. A direct comparison of winds at certain locations reveals a number of interesting facts. For example, in Figure 14 we see a comparison of the wind speeds for 1968 at the Columbia Lightship and at Astoria which are only 25 km (16 mi) apart. One would expect that the latter, being at the mouth of the Columbia River, would be shielded to some extent by nearby terrain features. Figure 14 illustrates just how pronounced the difference is: except during the late summer and early fall of 1968 the wind at Astoria was substantially less than that of the Columbia Lightship.

A similar comparison is presented in Figure 15, in which the winds for 1973 at Mount Hebo (a little less than 1 km, 3,180 ft) in height are shown with those for Astoria which lies 110 km (68 mi) to the north of Mount Hebo. Although the high winds on Mount Hebo are well known locally, it is evident that such high winds are largely limited to winter storms. The longer term annual winds for Astoria, shown by the broken curve, are presented to show that the 1973 Astoria winds are representative of long-term average weather conditions.

Comparison of Power Duration Curves for Various Sites. As indicated above, the wind-power potential of a site is conveniently represented by a power duration curve of the type shown in Figure 8. Such power duration curves are given in Figure 16 for three Oregon sites and two in Great Britain (Hewson and others, 1973; Hewson, 1973). The curves for Columbia Lightship, Cascade Locks, and Astoria are based on approximately 4, 7, and 5 years of data respectively. For comparison, two curves obtained from the very comprehensive wind-power survey made in Great Britain by the Electrical Research Association are shown. Rhossili Down, in western Wales, was among the best two or three sites found in Great Britain and that marked "Inland Britain" was one of the worst (Golding, 1955). A comparison of the power duration curves for the Columbia Lightship and Cascade Locks shows that there is more power in the higher winds at Columbia Lightship but less power in the lighter winds. The difference between the Astoria and Columbia Lightship stations, although they are only about 25 km (16 mi) apart, indicates how effective the coastal area is in reducing wind speeds.

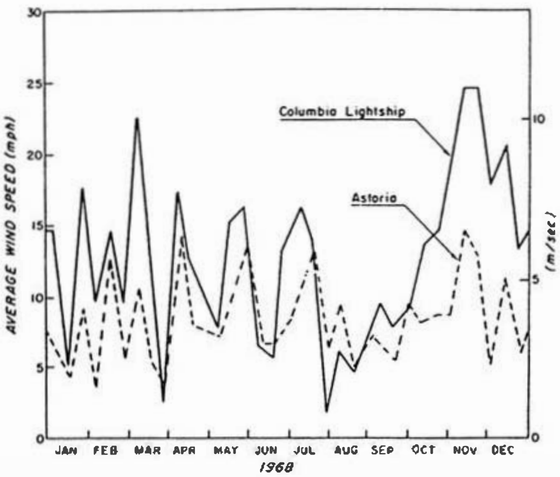


Figure 14. A comparison of wind speeds for 1968 at Astoria near the mouth of the Columbia River and at the Columbia Lightship, two stations which are only about 25 km (16 mi) apart.

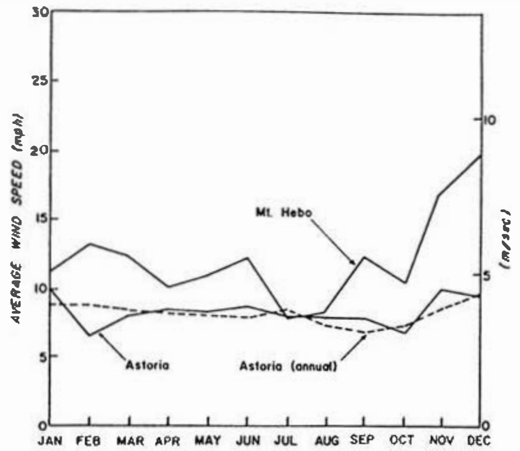


Figure 15. A comparison of wind speeds for 1973 at Astoria, near the mouth of the Columbia River, and at Mount Hebo, which lies 110 km (68 mi) to the south.

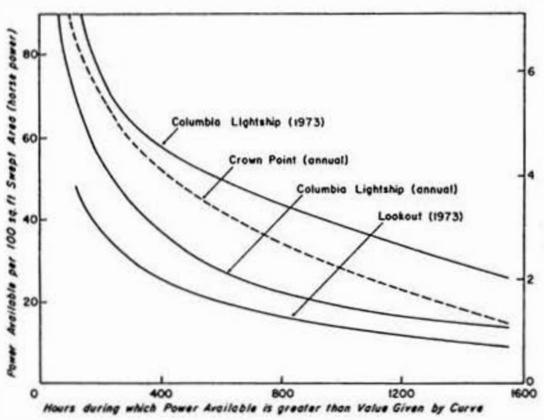


Figure 16. Power-duration curves for five sites, three in Oregon and two in Great Britain.

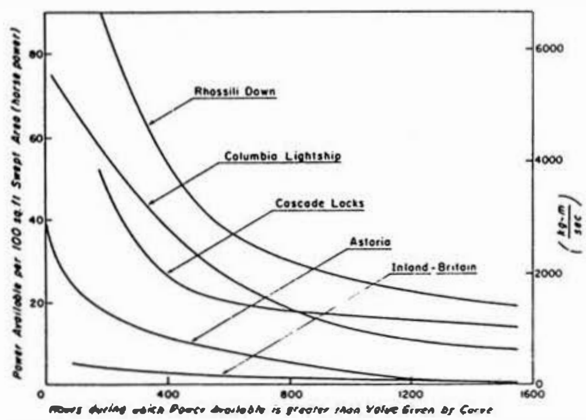


Figure 17. Power duration curves for various Oregon sites.

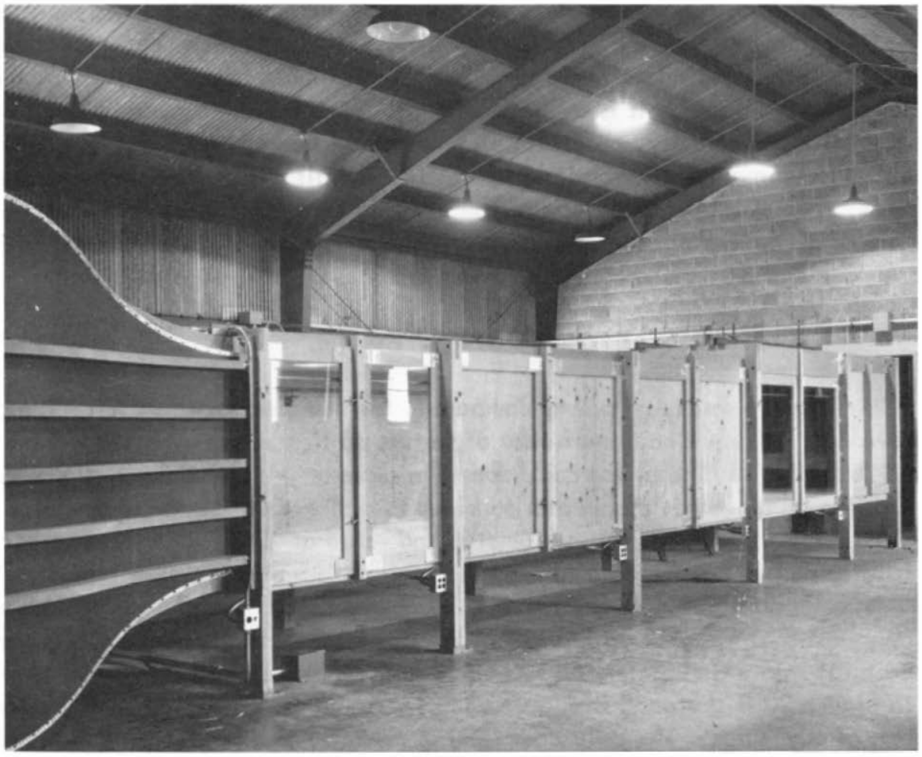


Figure 18. Wind tunnel to be used with models as an aid in site selection and in testing models of aerogenerators of various types.

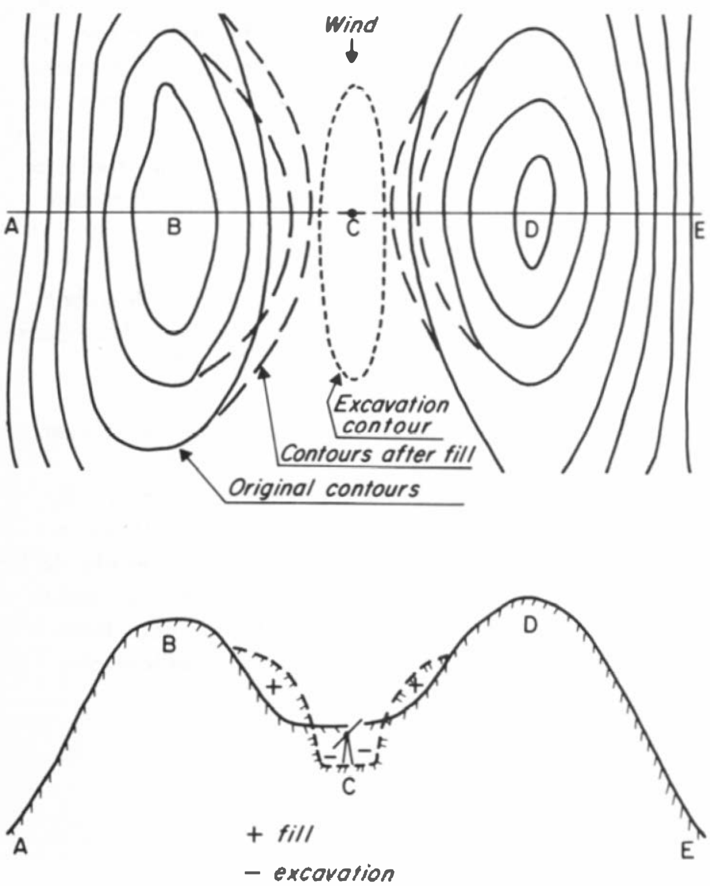


Figure 19. An example of terrain modification designed to increase power in the wind by increased venturi action.

The vertical rotor illustrated in Figure 20 is a variant of a vertical axis wind generator devised by the Finnish engineer S. J. Savonius (1931). From above it looks like a large four-cup anemometer of conventional design. Large hemicylinders rather than large hemispheres are employed, as the figure shows. Such a design has several advantages. It is omnidirectional, there being no need to keep a rotating blade system headed into the wind. Secondly, construction costs could be kept relatively low. For example, the hemicylinders could be conveniently obtained by cutting in half corrugated sheet-metal culverts of standard specifications. The chief disadvantage of the vertical rotor unit is its relatively low efficiency. This vertical axis type of aerogenerator merits further study. It is probably less vulnerable to severe turbulence than is the conventional horizontal axis wind turbine.

Aerogenerator "Farms"

The wind is a low-density source of power compared, for instance, with water. The density of air near sea level is approximately one-thousandth that of water, so that about a thousand times more air than water must pass through a turbine at the same speed to generate equal amounts of power. This means that wind turbines must be much larger than water turbines to achieve equal power output. The Smith-Putnam turbine with its blades 53 m (175 ft) in diameter and rated at 1250 kw at 13.4 m/sec (30 mph) shown in Figure 3 illustrates just how large a turbine is required to achieve a relatively modest power output.

If wind power is to be considered as more than a source of electrical energy for isolated homes and farms, it becomes apparent that arrays, or "farms," of wind turbines will be needed to generate enough power to justify feeding it into existing networks. A small "farm" consisting of sixteen vertical rotor units of the type shown in Figure 20 is sketched in Figure 21. The units are supported in a vertical position by an inexpensive system of guy wires. The only compression members are the vertical shafts of the rotors which are stiffened by the four hemicylinders.

Wind Turbines Above Coastal Waters

The possibility that offshore winds may be high enough to provide substantial wind power deserves further investigation. The power-duration curves for the Columbia Lightship shown in Figures 16 and 17 and the analyses of wind power potential off the east coast of the United States (Heronemus, 1972) both support this contention. Present cable technology is such that power generated a few miles off shore can be transmitted to the shore without serious line loss of energy if oil-filled cables are used. If more distant offshore sites are chosen, such as the Nantucket Shoals, or New York Shoals, or Georges Bank, it will be necessary to use the offshore winds to produce hydrogen gas which in turn is fed into fuel cells for conversion to electricity.

Types of Shallow-Water Aerogenerators. Two proposed three-wind-turbine aerogenerators are sketched in Figures 22 and 23. They were designed for possible installation in the shallow waters off the East Coast (Heronemus, 1972).

Wind Turbines in Shallow Pacific Coastal Waters. The shallow waters of the Pacific Ocean lying over the continental shelf off the coasts of California, Oregon, and Washington are also suitable for wind turbine installations. Figure 24 shows contour lines of ocean thickness for 10, 20, and 30 fathoms (18, 37, 55 m, or 60, 120, and 180 ft). The east-west scale of the contour lines is magnified five times in order to bring out details. The squares numbered 1 and 2 are wind-power farms, each approximately 16 km (10 mi) in the north-south direction and 3 km (2 mi) in the east-west dimension. They are represented as squares in the figure rather than rectangles because of the east-west magnification of the contour lines mentioned above. It is estimated that each farm would have an output of 500 mw, the equivalent of a small nuclear or fossil-fueled power plant.

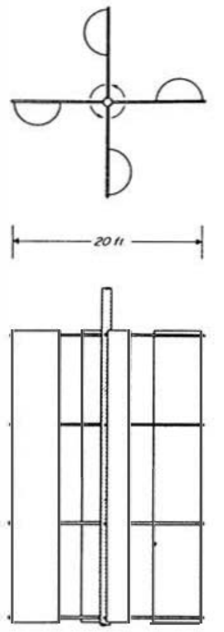


Figure 20. A variant of the vertical rotor aerogenerator first proposed by S. J. Savonius.

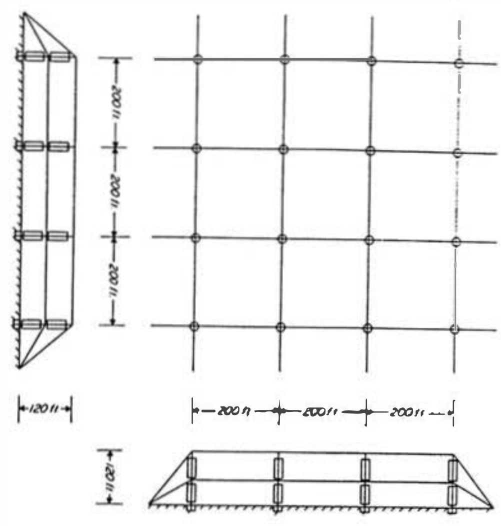


Figure 21. A small "farm" of sixteen vertical rotor aerogenerators.

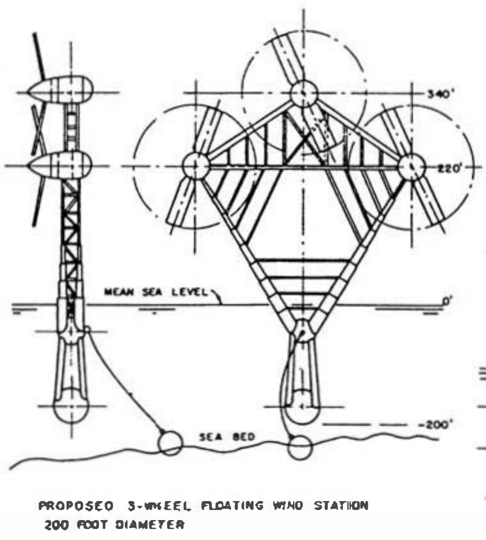


Figure 22. Anchored three-wind-turbine installation proposed by Heronemus (1972). The blades of each wind turbine are 61 m (200 ft) in diameter.

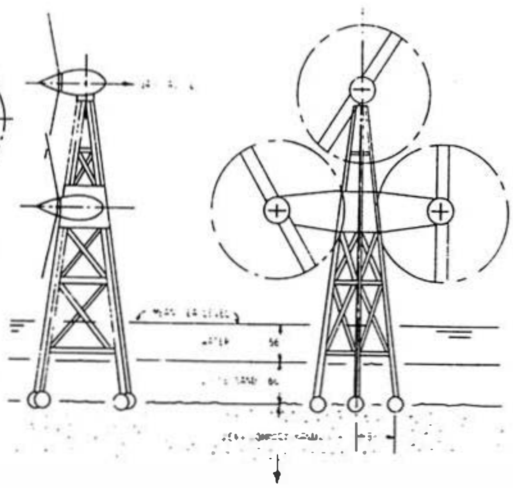


Figure 23. Seabed mounted three-wind-turbine installation proposed by Heronemus (1972).

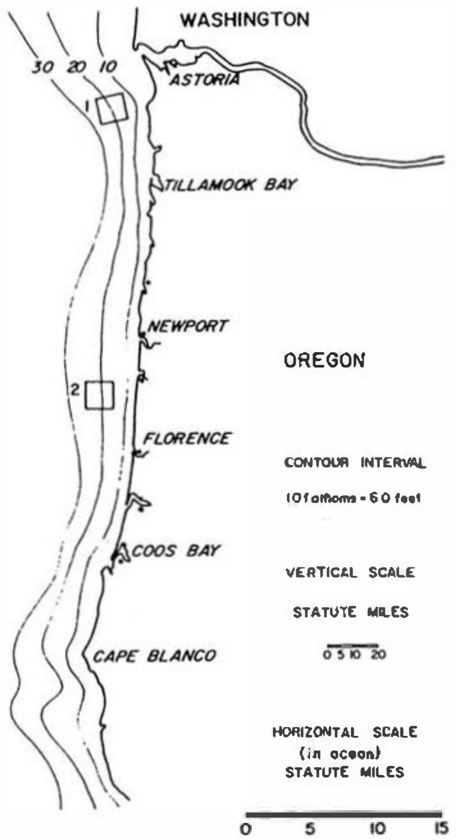


Figure 24. The Oregon Coast showing contour lines of ocean depth for 10, 20, and 30 fathoms (18, 37, and 55 m; 60, 120, and 180 ft).

Environmental Impacts of Wind Power

It is difficult to visualize a large source of electrical energy such as wind power which has fewer serious environmental impacts. The winds may be thought of as the flywheel of the giant atmospheric heat engine which is fueled by the sun. Just as the falling motion of water imparts rotation to a water turbine, so also does the horizontal motion of the winds impart rotation to a wind turbine. There is no rejected heat to be disposed of as with a fossil-fueled or nuclear-fueled power plant, only a conversion of a small amount of mechanical energy into heat energy as a result of friction.

Visual Pollution. Wind turbines must, of necessity, be large structures. Thus wind turbines such as those shown in Figures 1 through 5 do present a problem in visual pollution. The solution is to group such aero-generators in "farms" in locations where they will be seen by few people. There would be relatively little visual pollution by such wind-power farms at sites high on the sides of mountain valleys or in offshore coastal waters.

Land Use. Wind-power farms would, in general, occupy more land area than do fossil-fueled or nuclear-fueled plants, but the difference is not great especially if the required exclusion areas for nuclear plants are taken into account. The nature of wind-power generation is such that multiple use of the land, as for agriculture, would present few problems.

Influence on Winds. It is often asked whether or not the large-scale use of wind power might slow the Earth's winds sufficiently to cause a major change in climate. Such an environmental impact appears to be most unlikely. Even with maximum utilization of wind power with man tapping one ten millionth of the atmosphere's total energy, only 0.00001 percent of that total would be converted into energy for man's needs. It is unlikely that any appreciable influence on climate would be detected. The possible effect on climate may be thought of as the equivalent of growing a number of groves of tall trees. In a wind the branches of the trees extract energy from the wind as shown by their swaying just as the rotating blades of a wind turbine do. There may be a slight slowing of the winds for a short distance downwind, but nothing else.

Cost Estimates for Wind Power

It is relatively difficult to estimate the cost of wind power because mass production methods must be employed. If inflation only is allowed for, with no provision for use of space-age technology, it is estimated that a production run of 100 wind turbines of the Smith-Putnam design (Putnam, 1948) would cost $700 per installed kilowatt in 1970 dollars. In mass production technology, it is estimated that each doubling of the number of units in a production run leads to a saving of 20 percent. A very rough estimate is that, if modern space technology methods are employed and present day costs are used, 4,000 wind turbine units, each rated at 1 mw, could be built and installed for $600 to $700 per installed kilowatt. This figure is not greatly different from present day costs of nuclear power plants. It should be emphasized that the above cost estimates apply to land installations only. The costs for offshore installations are likely to be higher since they must be built to withstand severe winter storms (Nath and others, 1973).

An important factor in the cost of wind turbines is the amortization over a period of years. Precise information is not available on the life of the blades. But the blades may represent up to 40 percent of the cost of an aerogenerator. Costs will obviously be much less if the blades last 20 years than if they last only 5 years.

Net Energy Costs. If one is to make a realistic estimate of the comparative costs of various energy sources, it is necessary to take into account all the costs involved in the production of energy. For example, for coal-fired steam plants one should consider not only the cost of the plant itself but also the cost of mining the coal, transporting it to the plant, and removing the sulfur contained in it. Similarly the costs of mining and processing nuclear fuels must be taken into account in estimating costs of operating nuclear plants; even if much of the processing is done by the Federal government the cost is still borne by energy consumers as taxpayers. Consider strip mining of coal. The energy consumption in such strip mining is large. The energy cost of such strip mining should include the direct loss of agricultural production, the energy required to operate the large strip-mining machines, and the energy required to replace the soil and vegetation. When all such factors are considered, it may turn out that the net energy gained in burning strip-mined coal is not very large.

Applying the same criteria to wind power, we find that the significant cost is the initial cost of the aerogenerator. The energy cost in the various stages of fabrication should be evaluated carefully. If the blades can be constructed to last 20 to 25 years, then operational costs for that period will be very small. Fuel is free, in plentiful supply, and is completely renewable. There is no depletion of our limited resources such as coal, natural gas, and oil --resources which can never be reclaimed after they have been burned. There are many better uses for those organic materials.

Oregon Wind Power Sites

At the present time the Columbia River Gorge, and especially the higher elevations, appears to be the most attractive site for wind power installations in the near future. At these higher elevations, wind power farms would be seen by relatively few people, and hence would present little problem in visual pollution. At the same time they would be near some of the main transmission lines of the Bonneville Dam, so that electricity generated by the gorge winds could be fed into these with minimum construction of new transmission lines. If aerogenerators can be constructed to withstand highly turbulent winds, then such aerogenerators could be used at lower elevations in the Columbia River Gorge.

It is possible that there is more wind power to be extracted from the winds of the Gorge and the valley to the east of it than there is available at Bonneville Dam. This possibility deserves serious exploration.

A vast amount of wind energy is available in the offshore waters of the Pacific Coast, from San Francisco northward to and around Alaska. Such offshore wind power is likely to be more expensive than land-based wind power until suitable technology is developed for building offshore structures which can withstand severe winter storms and at the same time be reasonably economic. This is a major problem requiring further analysis if the high potential of offshore winds as a major energy source is to be realized.

References

Golding, E. W., 1955, The generation of electricity by wind power: New York, Philosophical Library.

Golding, E. W., and Stodhart, A. H., 1949, The potentialities of wind power for electricity generation (with special reference to small-scale operation): Leatherhead, Surrey, England, The British Electrical and Allied Industries Research Association, Techn. Rpt. W/T 16.

_____, 1952, The selection and characteristics of wind-power sites: Leatherhead, Surrey, England, The British Electrical and Allied Industries Research Association, Techn. Rpt. C/T 108.

Heronemus, W. E., 1972, Pollution-free energy from offshore winds, in Preprints, 8th Annual Conference and Exposition, Marine Technology Society, September 11-13, 1972, Washington, D.C.

Hewson, E. W., 1973, Wind power research at Oregon State University, in Wind Energy Conversion Systems Workshop Proceedings, Washington, D.C., June 11-13, 1973, Savino, J. M., ed.: Washington, D. C., NSF-RANN Program, NSF/RA/W-73-006, and Cleveland, Ohio, NASA-Lewis Research Center, p. 53-61.

Hewson, E. W., Davis, H. F., Nath, J. H., Thresher, R. W., and Wilson, R. E., 1973, Wind power potential in selected areas of Oregon: Oregon State University, Rpt. no. PUD 73-1.

Hutter, U., 1973, Past developments of large wind generators in Europe, in Wind Energy Conversion Systems Workshop Proceedings, Washington, D.C., June 11-13, 1973, Savino, J. M. ed.: Washington, D.C., NSF-RANN Program, NSF/RA/W-73-006, and Cleveland, Ohio, NASA-Lewis Research Center, p. 19-22.

Nath, J. H., Washburn, J. L., Mesecar, R. S., and Tavolacci, D. C., 1973, Offshore research tower: Oregon State University, School of Oceanography and Department of Mechanical Engineering.

Putnam, P. C., 1948, Power from the wind: New York, Van Nostrand.

Savonius, S. J., 1931, The S-rotor and its applications: Mech. Engineering, v. 53, no. 5, p. 333-338.

SOLAR ENERGY: HARVESTING THE SUNSHINE?

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Young people in school today hear a much-worn cliche that the world they face will be very different from the one we faced a generation ago; only this time there is deep substance to these words. The key factor that will make their world different is energy -- a growing scarcity of energy.

Almost 40 years ago I remember reading in school that natural resources would begin to be scarce in 40 years. It shocked me. I wondered what it would be like and if it really were so. Events now move apace in the drama we so faintly saw in the distance, yet most of the world's people still live outside that drama.

Perhaps the most dramatic comparison of the great span in living modes in the world is afforded by a look into the kitchen of the home. In Figure 1 we see a woman crouched by her clay stove in the corner of the hut feeding sticks and cow dung patties into the stove to prepare the daily meal. There is no chimney, and attempts to improve her lot have been rebuffed by the long-established customs and religion of her land, even though she will be blind from the smoke before her day's end. Social acceptance or non-acceptance of innovation is a powerful factor not fully appreciated in technological circles.

Even in our country social non-acceptance is quite apparent in inhibiting widespread installation of nuclear power plants, oil refineries, etc.

For comparison, in Figure 2 is a caricature of a modern kitchen. The lord of the house and his lovely lady are surrounded by every appliance ever invented, down to such little ones as the electric knife on the rack near the clock. If you look closely you will see next to the clock one not invented yet -- the electric fork -- known to most of you from a certain TV commercial, along with the folding water bed. The gentleman is saying: "I don't believe it -- that Mickey Mouse power company of ours is having another power crisis!"

In our prolific use of energy we have whetted the appetite of much of the rest of the world to copy our ways. Energy is the key to free man from a dispassionate environment. Nature can be very cruel to poor people unable to extricate themselves from the predicament of their birth; it is natural for them to want a share of the abundance that we enjoy for necessities and for those luxuries that are part of our standard of living.

In the above views of the two kitchens, we see the great gap that now exists. When we drove along the banks of the Ganges River a few years ago we wondered about the energy events lying in the future of each. A small village by this river is now so proud of its one electric light, qualifying it to be officially called an electrified village (Figure 3). Are they some day to enjoy our standard of living? Can the world support them also? Or is it inevitable that we must decrease ours as they increase theirs? The answer will come within your lifetime.

Soft sunset glows along the Ganges are not due to clear skies over this energy-underprivileged land. They are due to the evening cooking fires -- and cow dung smoke has a distinct fragrance to it. Low energy consumption and low industrialization do not necessarily mean freedom from pollution.

A few years ago the thought that we in America might have to reduce our standard of consumption because of depletion of our resources would have been dismissed by most people as sheer nonsense. Today things are different and we see a new concern expressed by many. Uncle Sam now finds his cornucopia of plenty just about out of many critical things. You name it: we're running out of it!

You even see ads by such companies as General Electric showing a lump of coal in a museum case, along with the comment that there is enough remaining for 300 years -- at the rate we are currently using it. But will we use it in the future at the same rate as today? The picture drastically changes when you look ahead. Immense new demands are already being made on coal as it substitutes for other fuels that are running out. Furthermore, much of our vast coal reserves lie deep in the ground in nearly unminable situations.

Figure 1

Figure 2

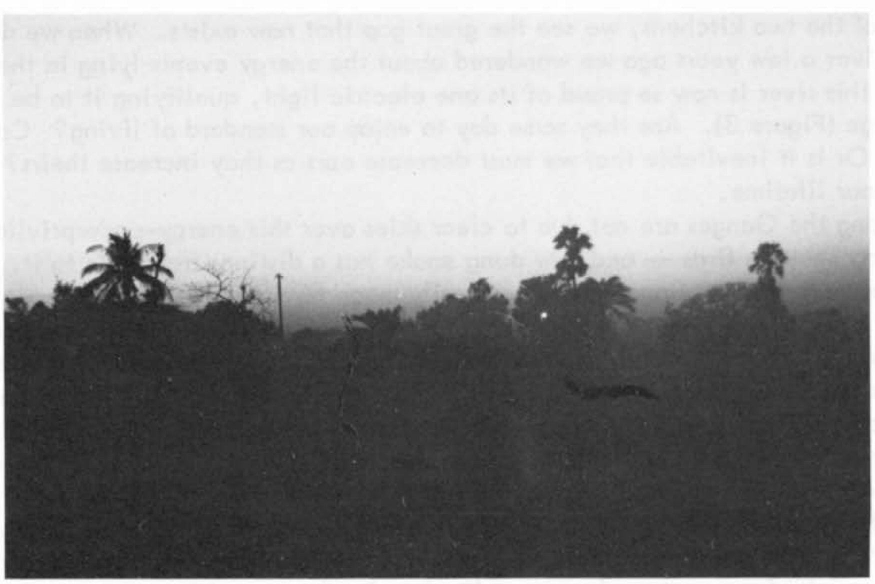


Figure 3

Figure 4

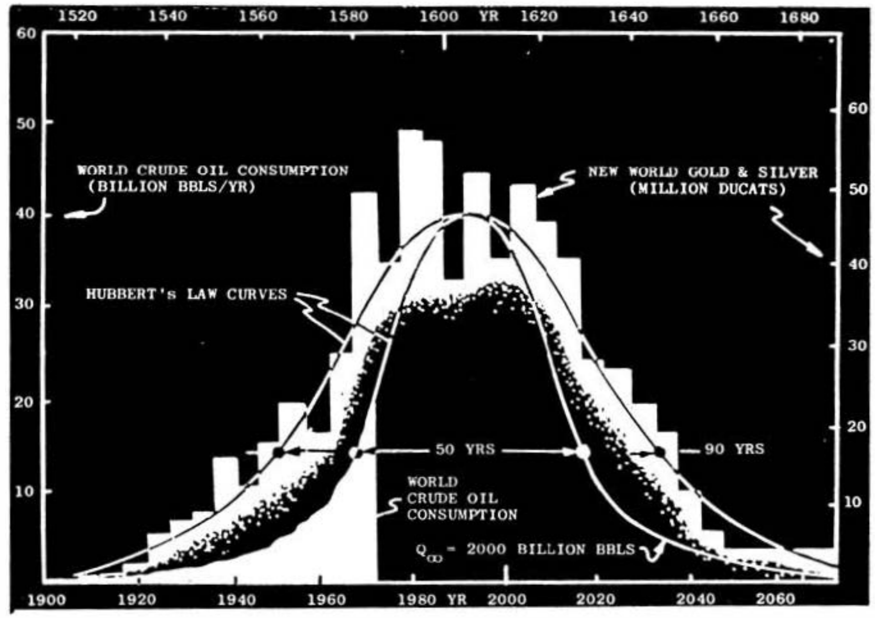


Figure 5

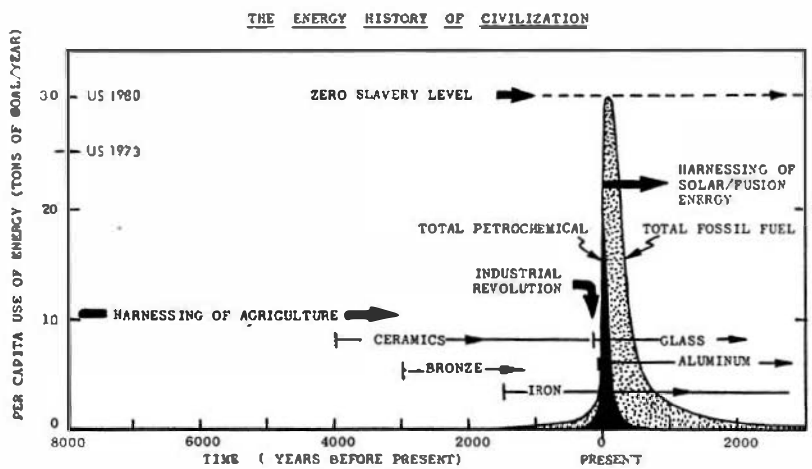


Figure 6

Who will choose to mine our coal? Not long ago we heard one of the energy chieftans (who has recently departed from the Washington scene) wonder aloud if Americans loved their energy so much that they would stand for conscription to man the coal mines! We don't think that many of you would relish two years of impressed service in the coal mines!

The United States has just completed the great adventure of going to the moon. Already, few remember the names of these lunar explorers, or how many trips they made, or how many pounds of moon rocks they brought back to the laboratories of the earth. To people in the years ahead, and to many even today, the most significant benefit of going to the moon was the new view it gave us of our own planet (Figure 4).

We now see the earth in a new light. It is a finite planet. Once our resources are gone we cannot leave it. There is no place to go. Our dream of colonizing our neighbor planets is gone. Venus, the twin in size to the earth, is so hot that lead would be melted on its surface. Radar now tells us it is cratered, like our moon, beneath its suffocating atmosphere of almost pure carbon dioxide. Mars, that tiny planet with polar caps, which looks like a small earth through a telescope, is also cratered from the early days of creation, and, like our moon, is not habitable either. It has but a trace of an atmosphere, devoid of oxygen, with temperatures that drop at night to 200° F below zero. We must love the earth -- we cannot leave it!

Some years ago the noted geologist, M. King Hubbert, developed a mathematical theory for the exploitation of a limited and valuable resource. All he needed to predict when a resource like petroleum would be gone was: 1) the total amount in the earth; and 2) the rate of increase of use over a small part of the lifetime of the resource. Most oil geologists and administrators ignored the conclusions that his theory predicted. We show his prediction in Figure 5, plus another example that lends support to his theory.

While we were in Nepal a few years ago we happened to be reading a history book we had taken along and came upon an interesting table of numbers. It was the return by the Spanish treasure fleet of gold and silver from the New World. We noted that it rose rapidly to a peak and then decreased as rapidly as it had risen. The bars in Figure 5 show the amount for the dates on the upper line. Here then is exactly the situation to which Hubbert's law should apply. The Aztec and Inca gold was a non-renewable and limited resource of high value to the Conquistadores.

When we plot on the same graph the increase in world oil consumption since 1900 we see it closely tracking a Hubbert curve. If we assume that the total world reserves are 2 trillion barrels -- which is equal to all known oil, including recoverable oil shale and tar sands -- the curve is as shown above. This means that the world will be down to a very small petroleum consumption in your lifetime. With it will go many things we hold dear to our hearts today.

The Conquistadores got quite a reputation in our history books for their rapacious treatment of the treasure of the New World. It took them 90 years to remove 80 percent of it -- but we will need scarcely 50 years to remove 80 percent of the world's petroleum. And remember -- most of that gold and silver still exists. That oil is now reduced to carbon dioxide and water and is gone forever.

History is a fascinating subject when you look at it carefully and when you seek the lessons it holds. When you show the history of civilization on one small chart, as in Figure 6, certain things stand out. We see on this scale how transitory our current surge of energy use could be.

We start this graph at 8000 years ago because this date marks a fundamental change in the way man lived. It marks the transition from plundering the earth for his food to replenishing it! He invented agriculture and he domesticated animals. This great discovery freed him from a nomadic existence tied to where he could find sustenance for his tribe. Cities became possible, since he could modify his local environment to renew his food and fiber. Energy, however, played a very minor role in those early days. What little mobile energy was needed could be economically met by animals and slaves. And so man lived until very recently.

On this graph we show the energy consumption per capita in terms of tons of coal per year. Today we in the U. S. consume the equivalent of 26 tons of coal per person per year. This is really why we have achieved a level of zero slavery. In most of the world the consumption is much smaller, and many people are still, in effect, enslaved to a world of sparse energy, uncertain food supplies, and the ever-present diseases.

On the above scale the petroleum age is but a tiny sliver. If we add all the coal and uranium, the curve is broadened but still tiny compared to the vast sweep of history.

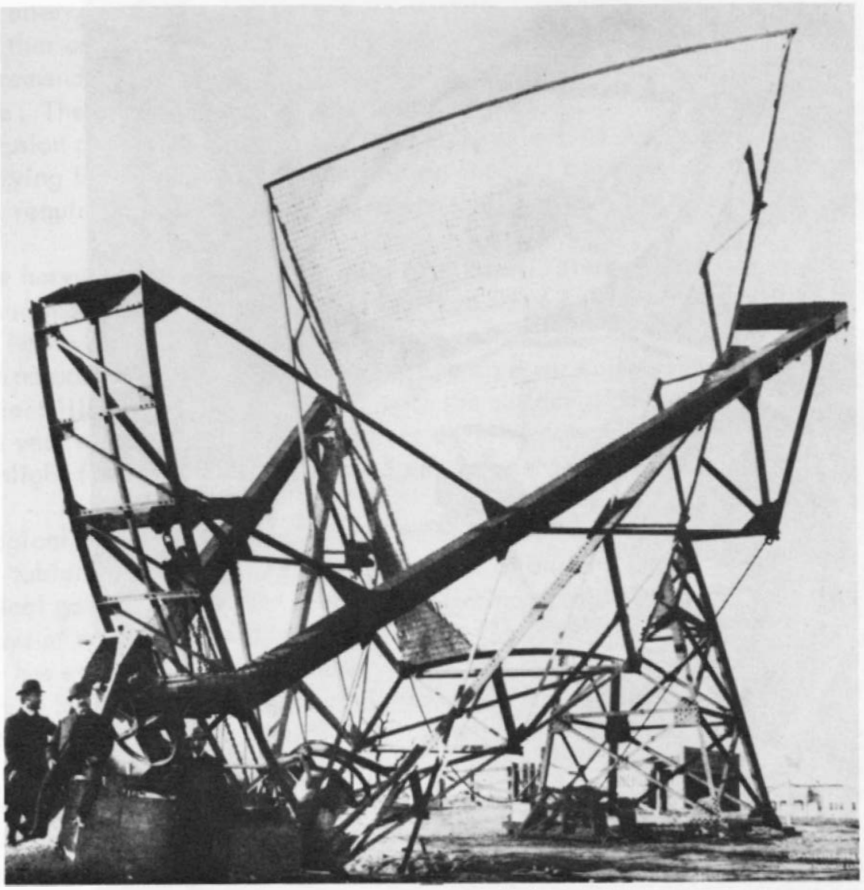
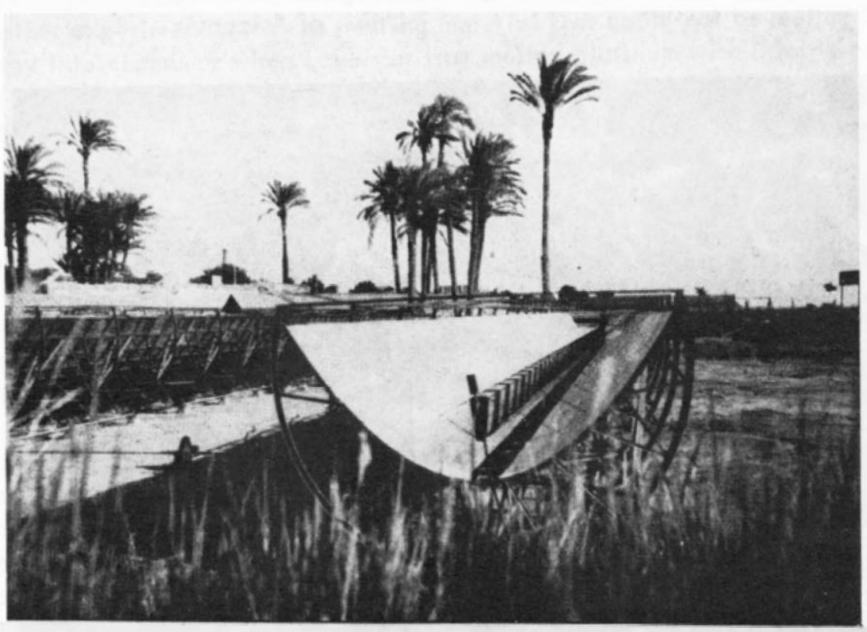


Figure 7



SHUMAN-BOYS ABSORBER, MEADI, 1913. ONE SECTION OF THE ABSORBER, FROM THE NORTH.

Figure 8

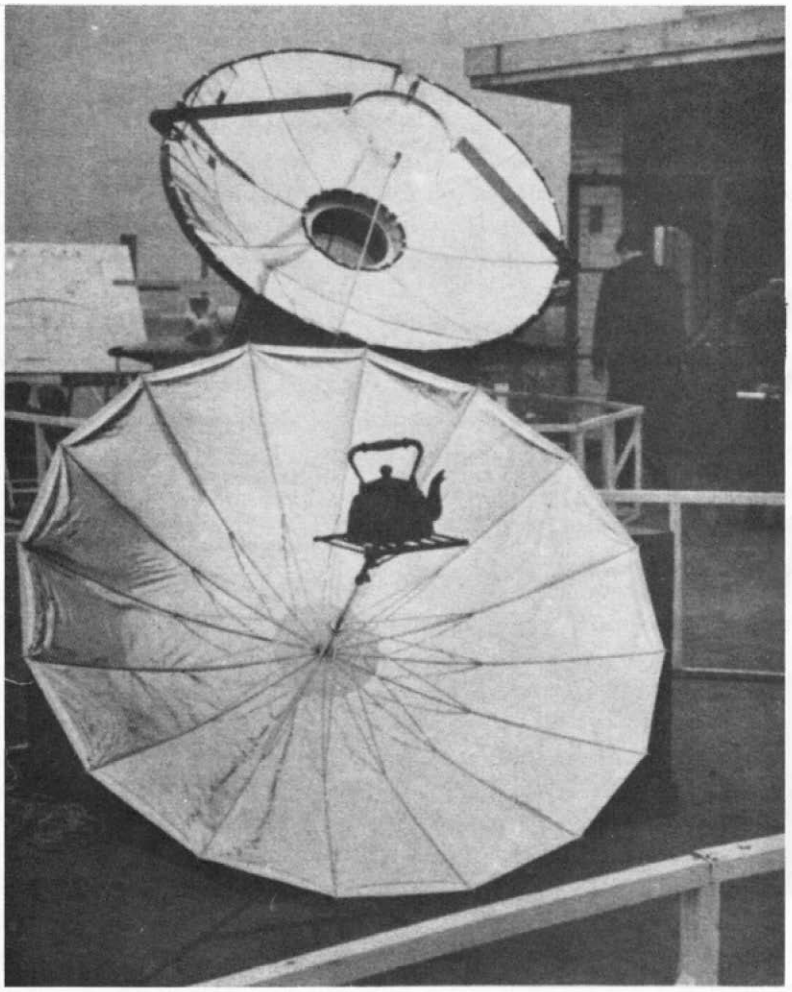


Figure 9 (Photo by George Kew, Optical Sciences, Univ. of Arizona)

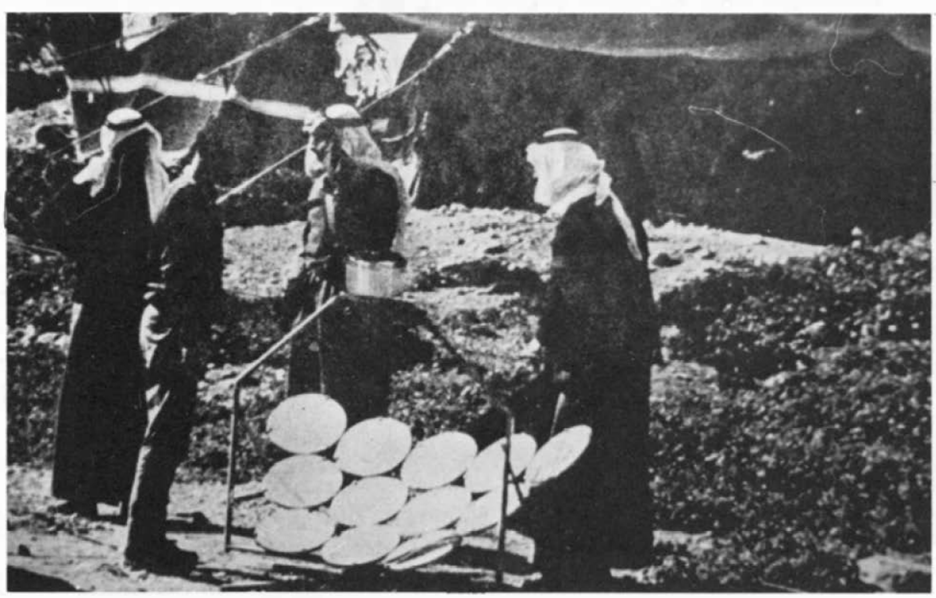


Figure 10

What are the alternatives that can extend the blessings of energy beyond this brief interval? There are really only two that are big enough and long-term enough to preserve civilization as we know it, and that can meet the tremendous task of winning from the depleted earth and our wastes those other resources necessary to our life. They are solar energy and fusion power.

The sun is a fusion power reactor. In the laboratory scientists are striving to create small models of the sun, but after trying for 20 years, controlled fusion reactors have not yet been invented. The sun already is working, requires no maintenance, is safely shielded from the earth, and will last as long as we need it.

Why can't we harvest our energy from sunlight? There is plenty of energy emitted from the sun. In one second it radiates more energy than mankind has used since creation, but most of it goes unused into space. The earth, however, intercepts each day more energy than man has used since the beginning. Some is slowly converted naturally into fuels, and the oil and coal we enjoy today is but the primordial sunshine transformed by ancient life and preserved for us under the surface of the earth.

The sun each year also grows our crops, a very useful renewable form of solar energy. But can we successfully use sunlight for creating other useful forms of energy to replace those fuels that will someday be gone forever?

The technological use of solar energy is not a new idea. Solar energy has been used occasionally as far back as clay tablets record. The temple priestesses of ancient Ur lit the sacred fires on the altars by lowering a cylindrical golden vessel over the votive offering, the walls of the polished vessel reflecting and focusing the rays of sunlight, igniting the flame.

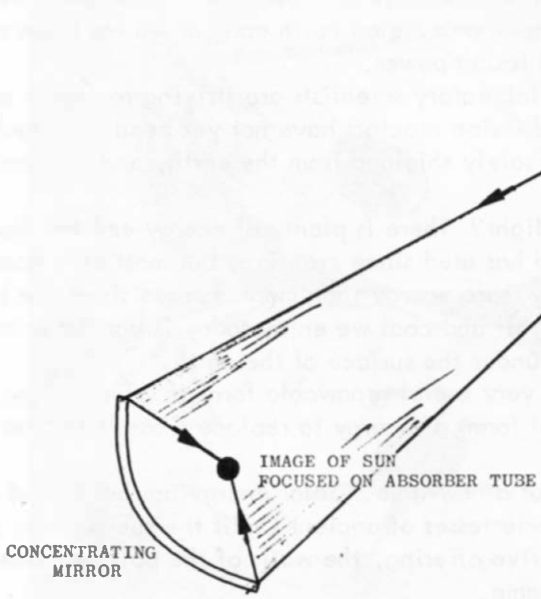
Solar energy has even been found in history as a defensive weapon. The first was by Archimedes at the Roman invasion of Syracuse. Archimedes was the chief scientist of King Hiero of Syracuse and one of the greatest inventors of all history. After being prodded by the King to put some of his marvelous speculations to practical use and save the city from its long siege, Archimedes came up with a novel defense for the harbor. He apparently lined the small harbor walls with soldiers, each of whom had a polished shield to reflect the sunlight. The net effect was to focus light from the early morning sun as it rose behind the invading Roman fleet. Some ships were set on fire, "whence the Romans" (according to Plutarch) "seeing that infinite mischief overwhelmed them from no visible means, began to think they were fighting with the gods."

Solar energy came back into human affairs in the Renaissance. When scholars read the classical authors, the story of Archimedes was discovered -- and doubted. Some of the earliest new experiments were made by people trying to set fire to things at a distance using mirrors. Solar heat then naturally came into use for other experiments, such as melting material that could not be melted by any other means. It even found its way into chemistry when Lavoisier first melted platinum with a large burning glass.

The surge of the Industrial Revolution in the 19th Century boosted solar energy along with other mechanical devices and engines. Figure 7 shows a large solar furnace built in Portugal at the end of the 19th Century. It is most impressive even by the standards of today's resurgence of interest in solar devices. An off-axis section of a parabolic mirror made of many tiny pieces of flat mirrors focused sunlight into the crucible at the lower end of the structure. Note the complex apparatus needed to track the daily motion of the sun to keep the focus in the crucible.

In Figure 8 we see the largest solar pump, built in Egypt by an American engineer and a British capitalist. It was the end of a fascinating line of solar engines and its date is very significant, 1913. In 1914 World War I began, and by its end a new technology had emerged into everyday use -- the internal combustion engine, operating on petrofuels. The new engine, by comparison, was quite compact; the vast oil discoveries in California, Oklahoma, and Texas had made fuels inexpensive; and so the petrofuel age dawned and the solar age died before it was even born.

Thirty years later solar energy had a brief but abortive attempt at a revival. After World War II, scientists who had played a prominent role in ending that war, culminating in the atomic bomb, looked around to see where they might next benefit mankind. The challenge of those years was the problem of the many small nations arising out of the wreckage of the colonies. Invariably, they were energy and resource underprivileged. Perhaps solar energy could be useful to them. As a result we saw many small gadgets designed by "us" for "them." Figure 9 summarizes the view of solar energy by many people during those years -- a tea kettle over an aluminized umbrella. Few really stopped to think of the social barriers to acceptance of these gadgets, or the fact that something cheap by our standards could be impossibly expensive to someone in those countries.



CONCENTRATING UNIT

WILL NOT WORK WHEN CLOUDY

Figure 11

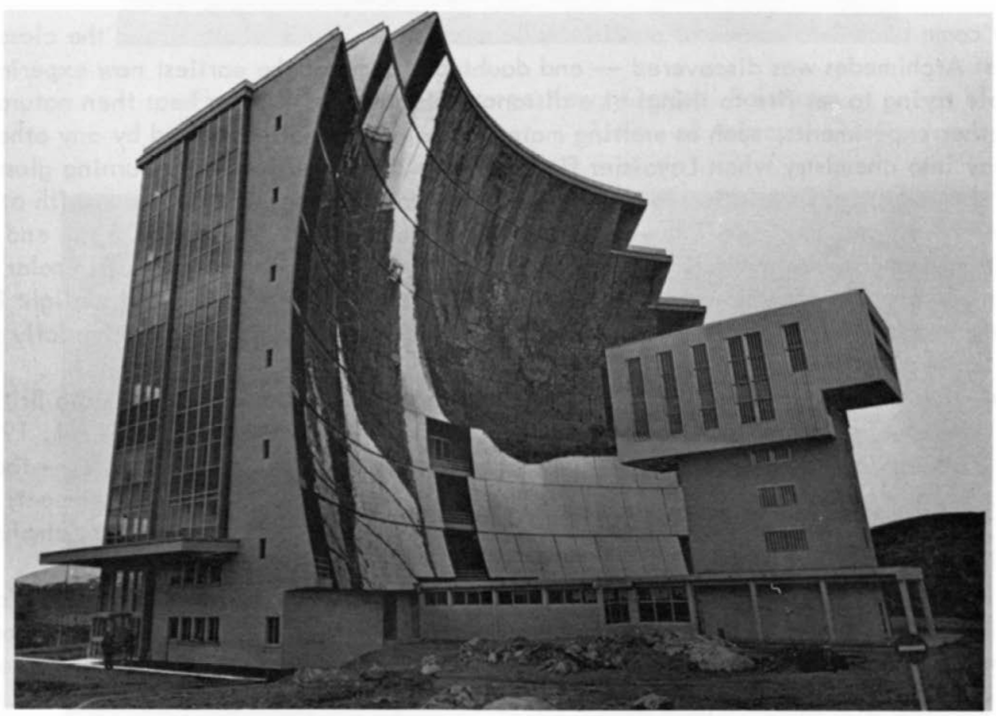


Figure 12

Figure 13

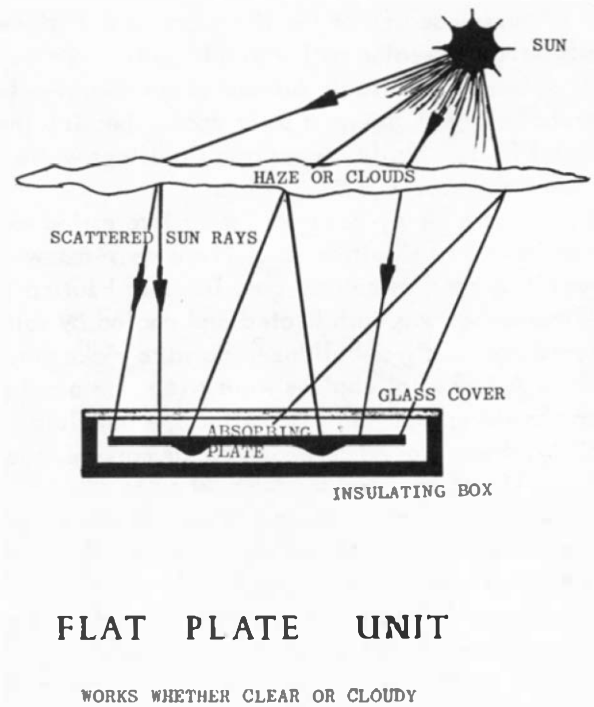


Figure 14

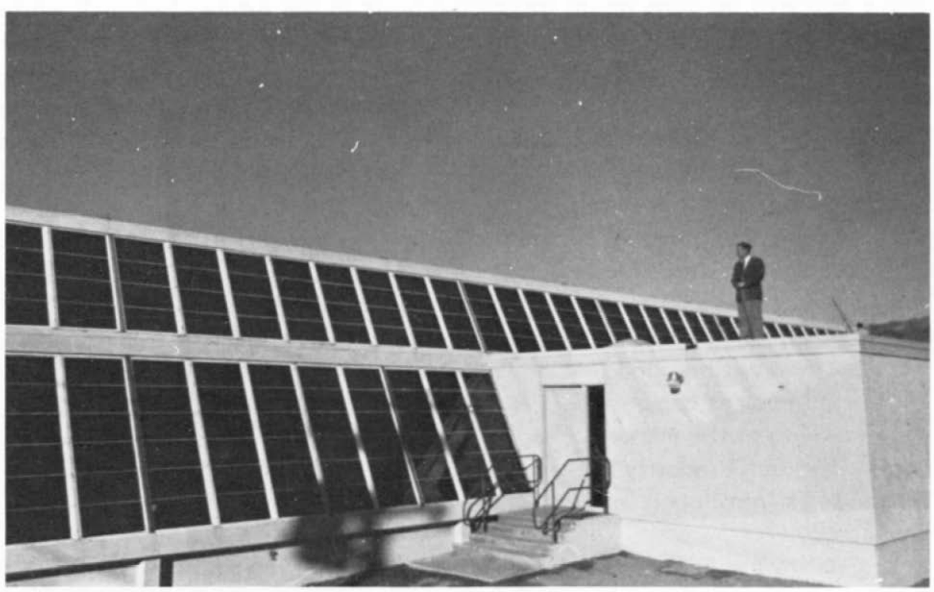


Figure 15

In our search of the literature to see why solar energy failed to get anywhere in the last two decades, other than the solar cell which in spite of its expense could be used on spacecraft, we came upon what we think is the most ironic picture about energy. In Figure 10 we see some poor, energy-underprivileged Arabs gathered around a solar cooker heating their lamb stew. Today they could be driving around that desert in their Rolls Royces and Cadillacs while we wonder if solar energy might be something to give us some energy.

There were, however, some interesting experiments in the ten years preceding the energy crisis that now have new significance. There were a few solar houses -- experiments that showed that it certainly wasn't as good as natural gas, but that heating could be done. We even had one at the University of Arizona that was both heated and cooled by solar energy, but interest in such houses was so low that five years ago ours was bulldozed down to make way for a new campus building.

A few solar engines were tried. In one in Israel, three large plastic cylinders focused sunlight on an absorbing pipe, which carried the hot fluid to the pump. While such devices proved technical feasibility, there was little economic demand for them and they withered away.

The largest and most recent solar energy installation, completed in the late 60's, is the solar furnace in the Pyrenees of southern France, shown in Figure 11. It focuses sunlight by that large wall of mirrors (from a battery of flat mirrors on the hillside out of camera range) into the cupola at the right where intense heat is generated. This unit is still used for high-temperature research, and it properly can be considered as marking the transition from the old concepts of solar energy to the one we see emerging today. The theme today is framed by the question: Is solar energy an option for the future of the world or is it still an illusion?

A basic problem with the use of sunlight is that, in spite of the immensity of the solar output, each day the flux is dilute by the time that energy reaches the earth.

The lead role in the resurgence of interest in solar energy in the United States has been assigned to the National Science Foundation. Their program encompasses a wide assortment of ways to use solar energy which can be grouped into two broad categories: biological conversion, and technological conversion. There are many individual ways.

In the biological category one is basically limited by the efficiency of natural processes in the conversion of sunlight. A good field crop, like corn or alfalfa, converts about 1 percent of the sunshine falling on the farm into a bulk energy crop. The dream is to find ways to significantly increase this efficiency, but to date the search has not borne fruit. The crop method, moreover, faces a basic world problem: most of the land, water, and nutrients to grow things are already or soon will be committed to food and fibre crops. New lands are scarce in all these ingredients. The conversion of domestic wastes into fuels is attractive and will be done on an increasing basis in the future, but such wastes are dispersed, and probably less than 10 percent of our energy needs could be met by re-processing domestic wastes.

Technological conversion is an area that appears promising. One hopes by technological means to greatly increase the efficiency of conversion, up to 10, 20, or even 30 percent. There are two basic methods. The first is direct conversion into electricity, as is done by solar cells on spacecraft. The second is thermal conversion, where sunlight is first converted into heat, either to be used directly as in house heating, or indirectly as in house cooling, or via steam turbines to produce electricity.

Solar energy has a long way to go to become important as an energy option. Where does it rank today? The answer is zero, or so close to zero that it can hardly be seen. It is scarcely more than a hobby for enthusiasts. We still do not know what the options are. Until recently conventional energy has been inexpensive and in abundance, so there was no need for solar energy. There is no solar energy industry; no manufacturers, no marketing organization, and finally, no service companies exist. All need to come into being before solar energy really becomes competitive. Yet we face the dilemma: the industry cannot develop until the market develops -- yet the market cannot develop until the costs are lowered significantly, and the costs cannot come down until industry and mass production are possible. For these intertwined reasons you now see legislative bills introduced in Congress to pay the costs of getting solar energy into use and the new industry started.

As solar energy gets started again, it is important to keep a perspective on the goals. Solar energy is not like going to the moon where, in spite of costs, it was a goal of national prestige. Solar energy is <u>not</u> a technological stunt, a point that seems obscured in the minds of some of the aerospace companies starting work in solar energy. There is no question about whether it can be done. The real question is: Can it be done economically? We therefore have four factors that need to be considered simultaneously:

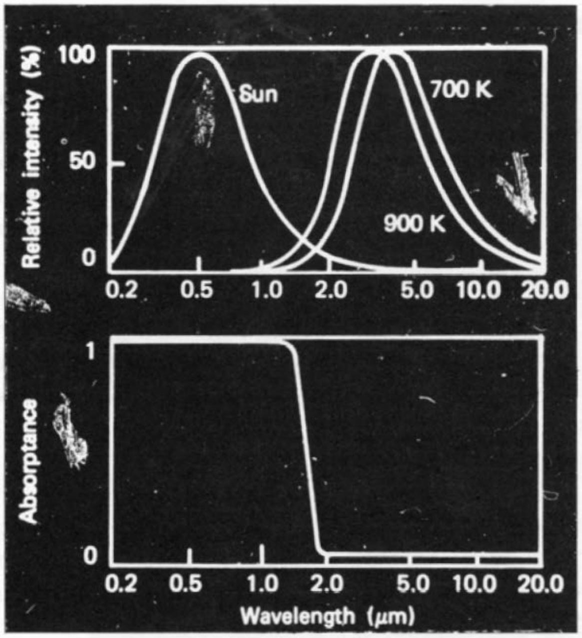


Figure 16

Figure 17

Figure 18

scientific feasibility, engineering implementation, operational adequacy, and finally economic reality. Until that last barrier is passed, solar energy will remain less of an option and more of an illusion.

We would now like to tell you something about how solar energy can be converted and show you some projects we have done. The basic ways sunlight is converted into heat are by focusing it to get high temperatures or by simply absorbing it on black surfaces when quantity rather than temperature is important. For swimming pool heating and home heating the simple black surface approach is sufficient. If higher temperatures are needed then additional technology is needed. One must either focus the sunlight or use sophisticated absorbing surfaces, described below.

Figure 12 shows the elements of a concentrating solar collector, where a curved mirror focuses the visible disc of the sun on a small receiving surface at the focus of the mirror. Such a collector works fine during clear weather, but when clouds or haze interfere, a focusing collector ceases to work well. Figure 13 shows one type of focusing collector we built to explore high temperatures for electrical power production, sponsored by four southwestern utility companies. It worked fine except when the sky became overcast, which is oftener than most people are aware, even in our desert climate of Tucson.

We have now turned our attention to the making of a type of solar collector that will work with bright cloudy skies. Yuma, Arizona, receives 93 percent of the available sunshine, most of it as direct sunlight. On the other hand, a place like Long Island, New York receives 63 percent of the available sunlight, but here more than twice as much is diffuse sunlight as is direct sunlight. One would like a solar unit that uses both the diffuse component as well as the direct component of sunlight.

A type of collector that works equally well with diffuse and direct sunlight, shown in Figure 14, is called the "flat plate collector." All light, regardless of where it comes from in the sky, is absorbed by the black surface. This surface must be carefully protected from losing heat, so it is always under a glass cover or two. In applications such as the solar-heated building shown in Figure 15, ordinary black paint is satisfactory to produce a temperature of about 160° F with reasonable efficiency. If higher temperatures are needed, we must resort to something more sophisticated than black paint.

Many years ago it was recognized by solar energy researchers that if one could make inexpensive "selective surfaces" one could still absorb sunlight as does black paint, but could inhibit the radiation loss associated with black paint. Nature is good to us in that she cooperates well, as shown in Figure 16. The energy of sunlight is concentrated at the left side of the graph, with maximum intensity in the green, coinciding with the maximum sensitivity of the human eye (0.56 μm). In the infrared, sunlight has little energy. A heated surface, on the other hand, has its energy loss in the infrared, well separated from the solar spectrum, as shown by the curves for two temperatures on the right. This means that one can hope to make a surface that has different characteristics in these two distinctly different regions. The lower curve shows the ideal surface, with high absorption for sunlight and low absorption, which means mirror-like, in the infrared. In other words, we need a black mirror.

There are many ways of making such black mirrors. One that produces the highest degree of selectivity is by vacuum deposition of alternating layers of metal, such as gold, and dielectric, such as aluminum oxide. Today these coatings are produced only in small laboratory quantities and their cost is high. When the quantities needed get large they will not be expensive, since the technology is simpler than that used in coating window glass for large buildings. This type of glass is used to control sunlight to aid in heating and cooling of these large all-window buildings.

There are simpler selective coatings that have sufficient selectivity to be useful in some types of solar collectors. These include chemical treatments of metal surfaces, like the tarnishing on silver, or electroplating techniques such as have been recently developed by NASA Marshall Space Flight Center, Huntsville. One can find several of the chemical treatments described in the ASHRAE Handbook "Low Temperature Engineering Applications of Solar Energy", 1967, 345 E. 47th Street, New York, N.Y., 10017.

To turn to matters that may be of more interest to many persons -- how can I use solar energy for simple things like heating and cooking? You can do quite a few things yourself without waiting for industry or government to do them for you. It does take a do-it-yourself person, and most people are not of this inclination. If you are, we refer you to a recent paperback reissue of a good book on solar energy, "Direct Use of the Sun's Energy" by Farrington Daniels, published by Yale University Press.

We would like to show you some projects we have recently completed. We wanted to personally find out how well these applications worked, as a response to many of the letters we receive. One question we get repeatedly is "Can I heat my swimming pool with solar energy?" The answer is "Yes, but

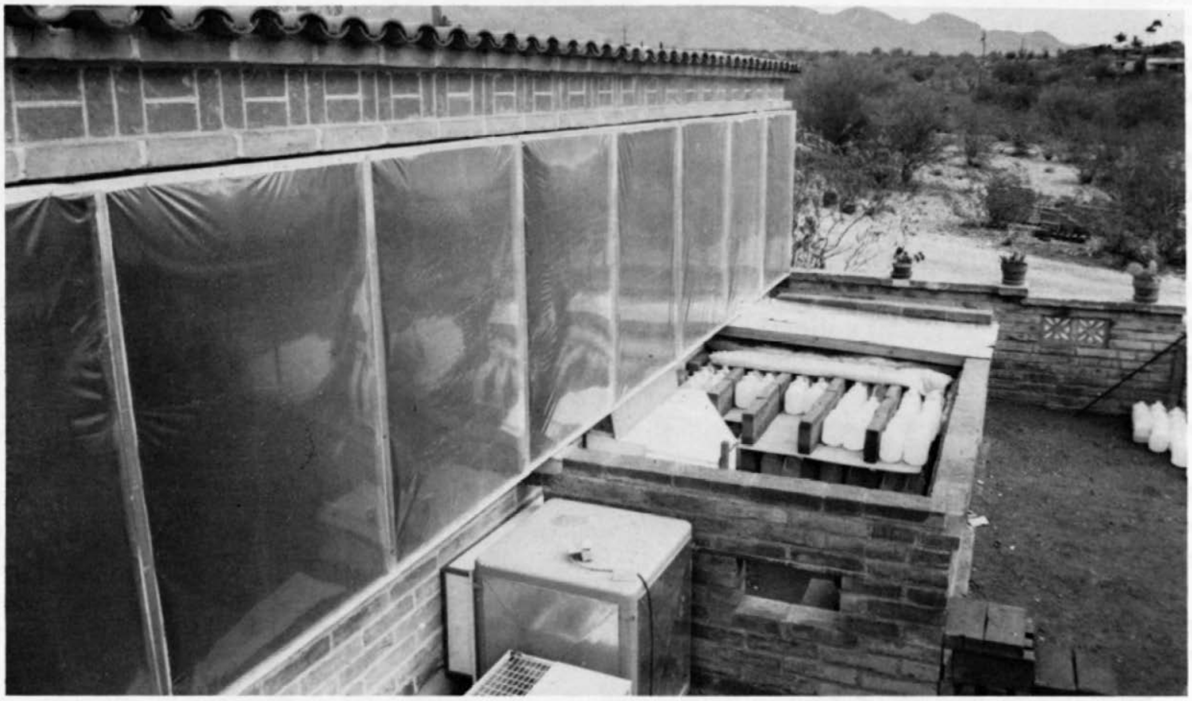


Figure 19

Figure 20

how big must the collector be to give satisfactory results?" We built a collector to find the answer. It worked but did not prove to be satisfactory. This collector has about the same surface area as our swimming pool, and it barely heated the water 5° F over what it would have been. The problem is that swimming pools are extravagant energy users. The heat you put in escapes quickly via radiation to the sky at night and by evaporation of surface water. The usual pool heater in Arizona, for example, is twice as large as is needed to heat the entire house in winter. If you want a swimming pool heater and don't want to be bothered with covering the pool each night, then you need a collector three times the surface area of the pool. We don't think solar pool heaters will be successful, even though some companies are offering them and people seem to be buying them. The reaction of disappointed owners is already showing up.

Our swimming pool heater was recently modified for house heating experiments, where hot water is collected and stored in a 300-gal. water tank under the solar collector. In general we were disappointed with practical aspects of this collector, such as the tendency for it to develop leaks due to daily thermal expansion of the collector as it heats and cools and to freezing, even in Arizona winter nights.

In response to many letters asking what the individual home owners could do this winter to stretch their fuel allocation, we experimented with a very simple collector that used hot air as the working medium. In this way small leaks are of no consequence -- they don't ruin furniture and walls. Figure 17 shows the first model, located on the south wall of our house in Tucson. It is an inexpensive and simple collector, whose inefficiency is well compensated by its low cost. The inner absorber is a black polyethylene bag sealed together to form air channels through which air is pumped and heated. The outer layer is a sheet of clear UV-stabilized polyethylene (Visqueen: Ethyl Corp.) to insulate the inner black bag. A small fan is placed at the bottom to flow air through the bag, and Marjorie is measuring the temperature of air coming out the top. The temperature regularly runs 90° F above the inflowing air temperature.

Figure 18 shows a better view of the air channels in the black bag. This type of collector does not look very pretty, but it does work. It worked well enough that we decided to make a better looking, permanent installation, shown in Figure 19. We also decided to use more reliable materials. One day when we didn't turn the fan on, the inner black bag got so hot it melted. When we came home and saw what we had forgotten, the black bag was a stringy sheet of melted polyethylene hanging down inside the clear window.

The improved model in Figure 20 has an absorbing surface of black-painted aluminum sheet. The adobe wall hides a thermal storage bin to hold heat for evenings and cloudy days. This collector looks a lot better, and it was enlightening to build. It showed us that the solar collector is only one minor part of the problem of a successful home-heating unit. In terms of cost, the collector was about 1/3, the thermal storage bin (filled with 1000 1-gallon polyethylene bottles filled with water, Figure 19) 1/3, and 1/3 for the modifications to the house forced-air duct system and addition of a control unit that decides what to do. The decisions are not as simple as with a regular house heating system where you set the wall thermostat and forget it. Here something needs to decide, for example, whether to send heat directly from the solar collector into the house, or if heat is not needed to send it into storage. If sunlight is not available, it must decide whether to draw heat from storage or turn on the house backup heating unit.

One fact you must face with solar energy is that it is impractical to store enough energy for the worst cloudy period in winter. You need a backup heating unit or you will go cold. It is this additional cost of solar plus a backup source of energy that further complicates direct use of solar energy.

Solar cooling units are not yet ready for use, but the principle of their operation is as old as the Servel gas refrigerator, familiar to many in the 1930's. The National Science Foundation expects to see first tests of combined solar heating and cooling units for homes by the end of 1976. Whether or not the economics will be right is still a question.

Although solar heating and cooling for the individual home is getting a lot of attention now, there are questions about how widely they will be used. Probably few people will want to be bothered with a bulky unit that doesn't look very attractive on their house. Nor will they want to pay any unnecessary costs for solar units when they can still sign up with the local utility for a nominal deposit and let the utility worry about the energy crisis. Our analysis says that home uses of solar energy for heating and cooling will be a disappointment to their advocates.

Commercial applications of solar heating and cooling may be more encouraging. In the first place, the units will be larger, and in the second place, most commercial businesses have flat roofs for inconspicuous placement of solar collectors. Figure 21 shows a model of a commercial unit designed in cooperation

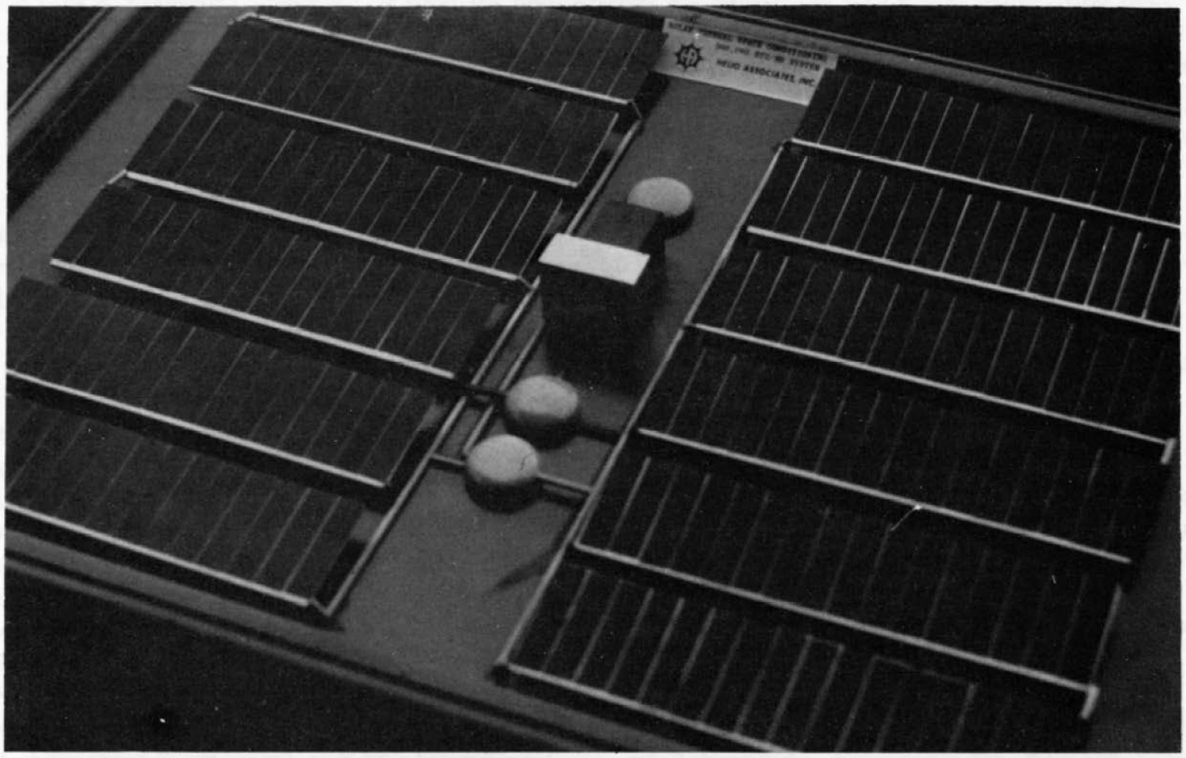


Figure 21

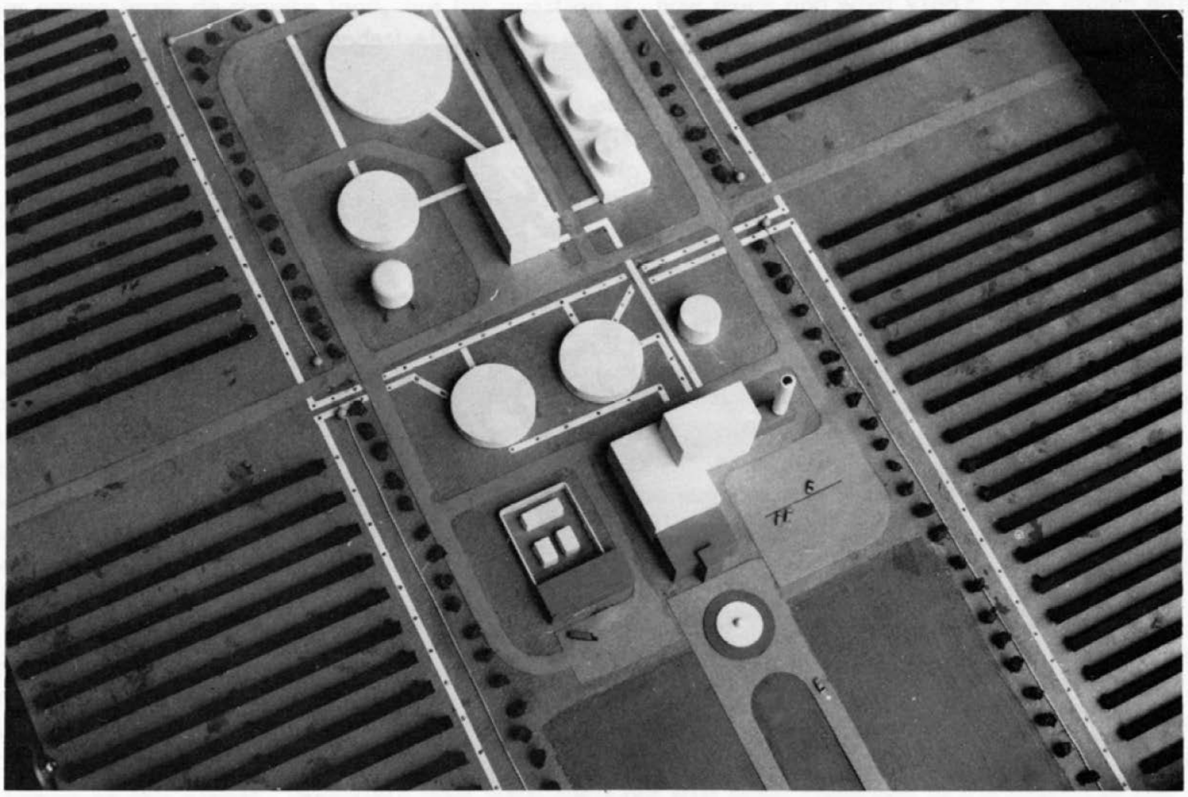


Figure 22

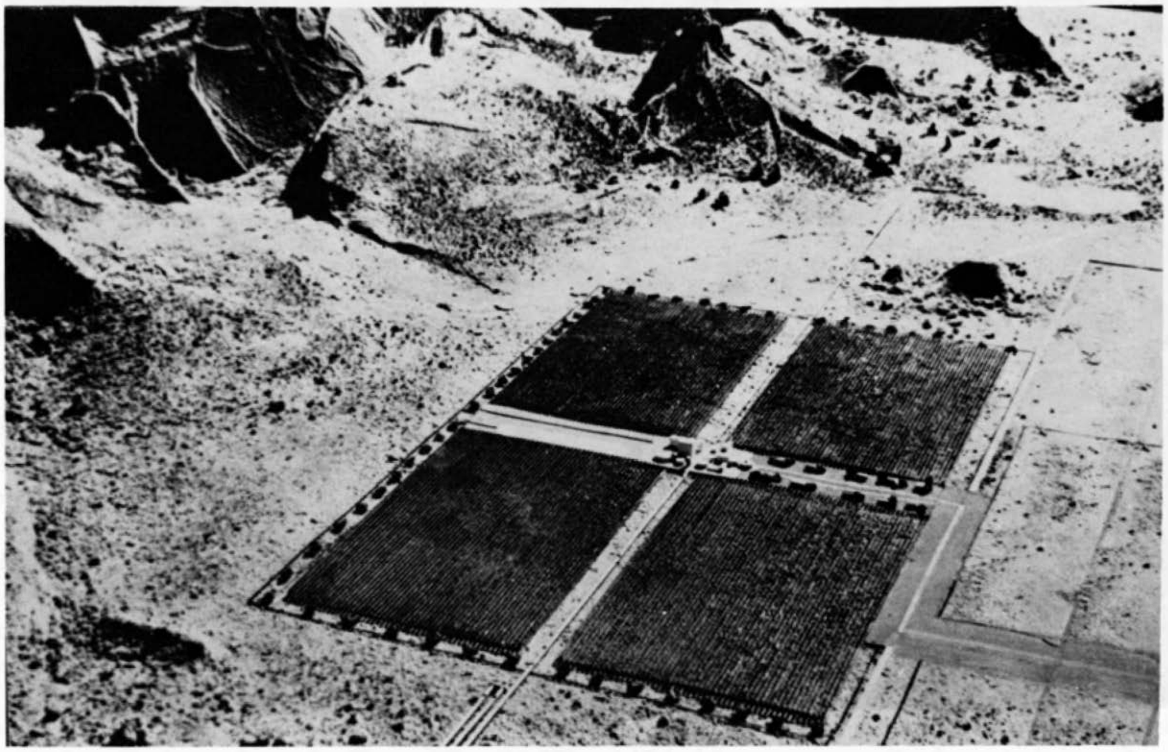


Figure 23

Figure 24

with Tucson Gas & Electric Company. It supplies heat energy for heating of space and water, and heat to drive a gas-absorption refrigeration system. The key to its introduction is cost. The utility company will have to show the customer that the solar unit on his roof will cost him no more per therm than if he stayed on natural gas. The ordinary economics of the introduction of new technology on small volume says that it cannot be competitive in the first 10 years. One answer is Federal support of these early installations, such as is proposed in the $50 million bill that just passed the House of Representatives and is now under consideration by the Senate. The other answer is to let the users of energy pay the introductory costs collectively. This could be done by allowing the utilities to apply the principle of co-mingling to include heat therms. In this way the customer who elects to stay on fossil fuel will absorb part of the added costs incurred by the customer who decides to do his part to ease the energy crisis by electing to use solar energy. Computer models of this situation indicate that a rise of less than 20 percent to the average utility bill over the first ten years would accomplish the task of transitioning from natural gas in Tucson to solar heating and cooling of commercial buildings.

The proposal for applying the co-mingling policy to heat is not particularly radical. This policy already applies to electrical power production and natural gas, where different costs of generation at separate plants within a distribution network are averaged. This means that electricity from a strip-mined coal plant, which is very cheap, can be averaged with power produced within a city by oil-fired generators. Extension of this policy to solar heat could be crucial in the success or failure of solar heating and cooling.

We think our proposal for solar power farms is the ultimate answer of how best to use solar energy. Solar power farms would be placed at some distance from the cities, just like other farms. Their crop would be electrical power, delivered to the cities via power lines. The user of this energy would not have to change the way he lives or thinks, and it could be used in any way he now enjoys.

A model of a solar power farm is shown in Figure 22. The power plant is located in the center where the heat from long rows of collectors is delivered. Some is used directly and the rest placed underground in pressurized tanks of hot water, to be used later to heat the vapor of the power turbines. You see that the rows are spaced. This is so that one row of collectors will not shadow the adjacent row for the early morning winter sun. If you now see the model of the farm from a greater distance, Figure 23, the solar power farm does indeed look like a farm.

Solar power farms do require land, but the question is, how much and what kind? One square mile of land could, with a solar unit of modest efficiency, provide 120 megawatts of electrical energy and be enough for a typical U. S. city of about 75,000 people. Tucson, with a population of 450,000 people and a power service area of 1,100 square miles, would need about 7 square miles of solar power farms, less than 1 percent of the area served. To many people this seems like a reasonable use of land, especially when there are more square miles than this of fill from copper strip mining within 20 miles of our city.

If we look at the need for land for enough solar power farms to meet the entire need of the U. S. in the year 2000, we find that about 15,000 to 20,000 square miles will be needed. This sounds like a lot, but really isn't by other farming standards. This corresponds to about 2 percent of the land currently under agricultural production in the U. S. and the land that could be used is land that cannot support any crop. Even the single state of Arizona could provide this amount of land with little impact. Just one bombing and gunnery range stretching from Yuma to Gila Bend has this amount of land. If the 20,000 square miles of solar power farms were spread over the 15 states with abundant sunshine west of the Mississippi River, there would be so few in any one area that you could not find one without a map.

The big problem between today and reality for the dream of solar power farms is, once more, the cost of the energy produced. At this point solar power will be more expensive than nuclear power, so a rather complex social decision must be faced. We hope that the combined talents of manufacturing and science will bring the cost of solar power down to a point where it is the logical choice for the way the world will generate its electrical power. That power will then be used to yield energy for people and fuels for their mobile vehicles.

When solar energy is viewed on a global scale we can see how small the land requirements will be. Figure 24 is one of the famous pictures from the Apollo program, showing the great deserts of the earth. Beside the earth are two squares. The smaller shows how large an area is needed in AD 2000 by the United States. The larger represents a great and noble goal: to provide the same per capita energy use we enjoy to every human on this planet, impossible from fossil fuels but still small compared to the deserts of the earth. One can easily conclude that solar energy is God's greatest gift of a natural resource for mankind and the key to a non-nuclear future for the world.

GEOTHERMAL ENERGY

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Geothermal energy, as the name implies, is the energy derived from the natural heat of the earth. Earth heat has been utilized by man to a limited extent since he first noted the warmth available from natural hot springs. In some areas of the world it was found that shallow wells gave temperatures as high as 300° to 500° F. The first turbine generator attached to one of these wells was at Larderello, Italy in 1904. Development at Larderello continued over the years, and today the field has a capacity of 380 megawatts and contributes a small but important part of the electric generating capacity of Italy.

Technology soon by-passed geothermal power development as it became more desirable to mine fossil fuels, transport them to the load centers, and produce the electricity near the site at which the electricity was to be used. Ten or fifteen years ago it seemed to be the natural progressive step to utilize the heat of the atom to generate the steam to spin the turbines, but in recent years, an environment-conscious society has taken a critical look at the energy industry -- including electric utilities -- and has forced many changes. One of these changes is a re-evaluation of geothermal energy as a possible power source.

Misconceptions About Geothermal Energy

Misconceptions about geothermal energy are rampant, and I would like to discuss these briefly.

I am sure that most of the people in the audience here today have heard it said that geothermal energy is in the same stage of development as the oil industry was a hundred years ago. That just isn't true; we know a great deal more about the earth, its processes and resources, than we did 100 years ago, or even 20 years ago. We have had some experience in geothermal exploration, many years experience in the utilization of geothermal resources, and have gained a vast knowledge of petroleum exploration, which utilizes techniques that are also applicable to exploring for geothermal fluids.

There is a widely publicized opinion that geothermal resources are limited to a few places - mainly those areas where it is being produced today. Actually, geothermal resources can be expected to be present under large segments of the earth and will be found under many conditions, just as oil and gas, uranium, and many other minerals have been found in areas not previously considered to have potential. The presence of usable geothermal energy depends upon the presence of three things: heat, water, and a geologic trap which consists of relatively impermeable rocks overlying a more permeable reservoir rock.

It is repeatedly claimed that geothermal power development will require significant technological break-throughs to be effective. Actually, 75 to 80 percent of the electricity produced today from geothermal sources comes from the simple, well-developed process of taking steam out of the ground directly from well bores and running it into a turbine. The only pre-treatment required is the removal of particulates by centrifugal separators. This well-proven method makes it possible to bring plants into production within a year or two after the steam is discovered.

There is a common assumption that the type of geothermal field producing electricity in the United States today -- that is, the dry steam or vapor intensive field as represented by The Geysers in California -- is unique on the West Coast. In fact, some say The Geysers is the only "dry-steam" field in the United States. Let me point out that the "uniqueness" of dry-steam fields is an opinion, not a fact. A classic example of this type of thinking was the discovery of oil in the mountains of Pennsylvania and West Virginia in the 1840's when it was generally accepted as fact that oil was unique to this region. The cry then was, "There will never be oil found west of the Alleghenies" - then it was "West of the Ohio" - then it was

"West of the Mississippi." The same thing happened with uranium. The experts said it was unique to a few places in the world, but exploration showed it to be far more widespread than anyone anticipated.

An Important Supplement to Energy Supply

I believe the idea of scarcity will turn into a realization of abundance for geothermal power whenever exploration can begin. But until we can start serious exploration, this abundant and cleanest of all sources of energy will remain a novelty. The key to the development of geothermal resources is not to spend massive amounts of public funds or tie up large blocks of acreage for special interest study but to make public lands available for exploration and development by industry under approximately the same guidelines as other energy sources are developed. As the Interior Department's rules and regulations are now written, there are far more restrictions on geothermal development than on the other energy sources. Such excessive regulation serves only the interests of those who benefit directly by the production of energy from other sources because it discourages a competitor who can produce geothermal energy at lower cost both monetarily and environmentally.

No single energy resource, including geothermal, can solve the energy crisis, but geothermal energy is available in Oregon and other western states; with proper incentives for exploration and development it can be brought into use to supplement fossil and nuclear fuels.

The Earth as a Heat Engine

It is only in recent years that the theory of crustal plate tectonics has been refined to the point where we begin to understand the processes that have produced and localized geothermal energy. The concept of crustal plate tectonics has revolutionized geologic thought including exploration for oil, gas and metallic minerals. Figure 1, a map of the world, shows where crustal plates have been either pulled apart or pushed together in recent geologic time. Pulling apart, or rifting, forms new crust by allowing vast flows of lava to pour out of the earth through fissures or erupt from volcanoes, as is happening in Iceland today. Pushing together causes the collision of one plate with another and is probably the more important process in development of geothermal resources. Along the zone of collision, one plate tends to dive under another plate and be subducted (or pulled down). Above the subduction zones are areas of intense geologic activity: mountain building, volcanism, earthquakes, and intrusion of magmas. The

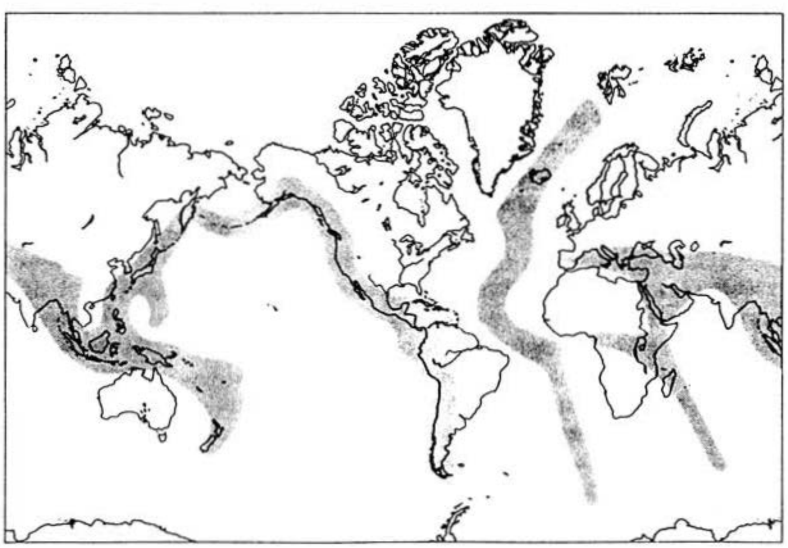

Figure 1. Shaded areas show volcanic belts associated with volcanic ridges or crustal plate boundaries.

Ring of Fire that surrounds the Pacific Ocean--the area in which we are most interested--is a subduction zone in some places and a rift zone in others.

The earth is a tremendous heat engine that accomplishes work. The motivating force is the decay of radioactive minerals deep within its heart, the work is the movement of the gigantic plates, and the product is the waste heat radiated out into space.

A few simple calculations will show that the amount of heat energy contained within the outer 10 kilometers (6 miles) of the earth's crust is greater than that believed to be in all of the fossil fuels on the earth. Scientists in the past realized the presence of this vast amount of energy but felt that most of it was too diffuse to utilize. The theory of crustal plate tectonics has changed this concept and has shown that most of this energy is contained in relatively restricted areas.

Temperature increases with depth at an average rate of about 30°C/km (1.6° F/100'). This gives a lot of heat in storage, but because of its relatively low temperature it is quite diffuse and not very usable. But in possibly 10 percent of the land surface, the gradient is about 60° C (3.2°F/100'). It is believed that most of Oregon from the west edge of the High Cascades to the eastern border of the State falls within this zone, and it is here that our high-temperature geothermal resources lie. From our present state of knowledge, it seems reasonable to believe that within about 10 percent of the high-heat flow zone, or 1 percent of the land surface of the earth, the geothermal gradient is in the neighborhood of 80° C/km (4.4°F/100'), and throughout eastern Oregon we have found many readings of this order or greater.

The amount of heat localized in that one percent of the land surface to a depth of 6 miles and at a temperature greater than 190°F is about 17×10^{25} Btu's. We can get a better understanding of the magnitude of these resources by comparing the energy resource base to that of coal, our most abundant and best identified energy resource. Within the United States, coal reserves of 3.2 trillion tons have been calculated to a depth of 3,000 feet, the general limit of economic mining. This volume would have a total energy content of about 7×10^{19} Btu's , or one ten millionth of the heat energy contained in the geothermal areas. An even better perspective of the enormity of these numbers is obtained by comparing them with the total consumption of energy in the United States, which in 1970 amounted to 6.8×10^{16} Btu's, or about one thousandth of our identified coal resources.

Geothermal Reservoirs

There are two basic types of geothermal reservoirs: hot water and dry steam. These constitute the drilling targets in which the geothermal resource is localized sufficiently for utilization. Our knowledge about these reservoirs is quite limited, but some ideas and theories are starting to develop. One important theory to explain the origin of the dry-steam reservoir suggests that through time the hot-water reservoir self-seals, blocking out incoming water. Then a lowering of the water level by leakage creates an expansion chamber in which steam can flash and eventually form a dry-steam reservoir.

It is interesting to note here how the geothermal reservoir, particularly the dry-steam reservoir, resembles a recently discovered phenomenon called the "heat pipe." The heat pipe is a very effective device for transferring large amounts of heat. It accomplishes this by using the generation, circulation, and condensation of steam to move the heat energy. Heat pipes have replaced other methods of forced cooling of devices that need to dissipate heat, such as large computers. Also, heat is transferred in industrial processes using this principal. The geothermal reservoir is a natural heat pipe.

Oregon's Potential

Now that we have an idea of what these geothermal reservoirs are, let's turn to Oregon and, by using the techniques developed for estimating resources and reserves in the petroleum industry, estimate what we might expect for Oregon. The technique is to estimate the amount of petroleum present and extractable in unknown areas by using experience from known regions.

In the Western United States about 1,200 hot springs are known. These could represent 600 geothermal systems or reservoirs. Let me mention here that many of the persons working in the field of earth heat flow believe exploration will reveal more geothermal systems that lack surface expression than those that can be seen at the surface--experience in the petroleum industry has shown this to be true. World-wide experience so far has shown that about 12 percent of the geothermal systems discovered produce all or significant amounts of dry steam. Using that experience number, we should expect 72 dry-steam systems in the Western U. S. Using The Geysers as a standard where we do have some experience, let's assume the following:

25% are the size of The Geysers at 4,000 MWe	= 72,000 MWe
25% are 1/4th size of The Geysers	= 18,000 MWe
50% are 1/10th the size of The Geysers	= 14,000 MWe
	104,000 MWe

Let me point out here that I am talking only about the so-called dry-steam fields that can be developed with present technology; no technological break-through or massive research effort is needed. Such fields are similar to the Lorderello and The Geysers fields, which have operated for many years. If 12 percent of these geothermal fields are of the dry-steam type, the other 88 percent will produce hot water that can be used for many purposes including production of electricity with only minor improvements in the existing technology, as is presently done in Mexico, Japan, New Zealand, and Russia.

In Oregon, we have about 200 hot springs, or 1/6th of those known in the United States, and in addition we probably have about 1/2 of the recent volcanism. This illustrates there is a great amount of heat underlying our State. I believe it is reasonable to estimate that we could expect to find at least 20,000 MWe of dry-steam geothermal energy in Oregon.

Cost of Operation and Production

Many years of world-wide experience in the production of electricity from geothermal resources show that the costs involved can be considerably less than for other types of thermal plants, and even less than for some hydroelectric plants. This is because of the over-all simplicity of the geothermal power-production cycle. Costs of finding and bringing a geothermal field into production can be estimated from numbers developed in petroleum exploration and from experience records in a producing geothermal field.

Costs to develop a prospect will range upward from a minimum of $50,000, but $250,000 is probably a reasonable figure for 2,000 to 20,000 acres, enough to be considered a good prospect. At least two wells are needed to evaluate the prospect, and these at a cost of approximately $350,000 each. This means spending a million dollars to put together and evaluate a prospect. Out of ten evaluated prospects, at least one and possibly two geothermal fields can be expected. That amounts to 10 million dollars and a lot of money, but let's put it into perspective. If it costs 10 million dollars to strike usable steam, then exploration costs, with amortization at 15 percent per year, would be 0.187 mills/kwh for a 1,000-MW field. Not a very significant figure considering that fuel costs have been escalating at 1 to 2 mills per year. Experience at The Geysers indicates that in order to produce sufficient steam for 1,000-MW plants (and this would probably consist of a mix of 100 and 200-MW stations), 150 to 175 wells would have to be drilled at an average of $150,000 each for a total investment in wells of about $25,000,000. Steam transmission lines could be expected to cost $15,000,000 and roads and landscaping $5,000,000. This would mean a total investment in the field of about $55,000,000.

Assuming amortization at a rate of 15 percent a year, fixed charges would amount to $8,250,000 per year, royalty to landowners, at 0.5 mills/kwh, would be $4,000,000 per year, and up to $6,000,000 would probably be necessary for field operating and maintenance costs. That gives a total energy cost of about $17,000,000 to $18,000,000 a year for 8,000 hours of operation, or 2.2 to 2.5 mills/kwh.

The costs for developing the steam field and the costs of steam per kilowatt hour of electricity produced are tabulated on the following page.

TOTAL STEAM COSTS
1,000 MWe Geothermal Field

Exploration	$10,000,000
Developmental wells (150-175 wells at $150,000)	25,000,000
Steam transmission lines (at $15/kwh)	15,000,000
Roads, landscaping, etc.	5,000,000
	$55,000,000

STEAM COST PER KWH
1,000 MWe Geothermal Field

	mills/kwh
Fixed charges $55,000,000 at 15% = $8,250,000/year $ 8,250,000/8 × 10^9 kwh	1.03
Royalties to landowners	.5
Field operating and maintenance costs $5,500,000/8 × 10^9	.67
	2.2

Pacific Gas and Electric is currently paying about 3.5 mills at The Geysers, but new contracts are being negotiated in the range of 5 mills for steam delivered to the power plant.

The question most frequently asked by those not familiar with geothermal development is "What is the life of the field?" That can best be answered by explaining what we know about geothermal fields and from experience developed in petroleum reservoir technology. That is, that steam in the reservoir behaves according to the same physical laws that apply to natural gas. This become apparent at The Geysers when developers were faced with the problem of proving sufficient steam for PG&E to amortize its plants over the normal 30-year period. The early practice had been to drill all the wells necessary to supply the proposed plant and to run lengthy tests to see how much draw-down was caused by the freely flowing wells. When it was found that the steam behaved like natural gas, this original practice was discontinued.

Now the procedure is to drill two wells in the region where a new plant is planned, and from that information ascertain the size and character of the reservoir. No longer is it necessary to put so much capital into numerous wells before starting plant construction; instead, production wells can be drilled while the power plant is being built.

Experience has shown that the wells decline with time but that the individual wells last 10 to 20 years. When production declines to the point where those wells can no longer produce all the steam required by the plant, new wells are drilled between the original ones, thus restoring production. It is now the practice at The Geysers to drill wells on a 40-acre spacing with the intention of filling in as production declines. All of the work to date shows this decline is predictable and the fields will last 30 to 50 years, long enough to allow amortization of the plants.

Environmental Factors

The potential environmental problems arising from geothermal developments are similar to those of any other industrial operation. The construction of roads, drilling of wells, and installation of pipelines and power plants all contribute to the changes in land-use patterns for the particular site. The effects on the land vary, dependent upon the type of fluid and utilization.

There is less environmental impact from producing electric power from a geothermal plant than from other types of thermal power plants, and in many instances less than from a hydroelectric plant when the dislocations caused by massive construction are considered. In geothermal power production, all of the steps of the fuel cycle are localized at the site. Other types of thermal power plants require considerable industrial support in the form of mines, transport facilities, and processing plants; thus the environmental impact of the fuel cycle for these operations extends far beyond the bounds of the power generating plant.

The "dry-steam" or vapor-intensive type of geothermal electric power plant has a long history of production experience based on the Larderello. The Geysers, and Matsukawa fields. For these areas, the only continuing environmental abuse has been the release of hydrogen sulfide gas, which has an unpleasant odor even in small amounts. The odor of hydrogen sulfide from a geothermal plant is more objectionable than the odor of sulfur dioxide from a coal-fired plant; however, the amount of sulfur released per unit of power generated is less. The Environmental Protection Agency limits sulfur emission from fossil fuel plants to 1.2 pounds per million Btu's. The Geysers releases less than a quarter of the EPA limits.

Because of the remote location of geothermal plants and the relatively small size of the operation, the release of hydrogen sulfide gas has not been considered a serious problem. However, as the size and number of plants increase it will be of greater concern, and studies are under way to alleviate it.

At The Geysers, Pacific Gas and Electric is conducting an emission abatement program that is expected to scrub 90 percent of the hydrogen sulfide out of the noncondensible gases. The company plans to start adding this equipment to the new installations and begin a program of retrofitting on the older equipment.

The major gaseous release from geothermal plants is carbon dioxide, but here again the release per unit of power is much less than from any fossil fuel plant. Moreover, the geothermal plant releases no oxides of nitrogen, smoke, fly ash, or other aerosols.

Some routine operations in geothermal steam fields are extremely noisy. In the past the process of well clean-out and testing generated large amounts of noise, sometimes continuing for long periods. At present the major noise is episodic and occurs only during the initial testing period when a productive well is first opened to clean the rock and other debris from the well bore. The noise normally lasts for only a few hours; as soon as the well stops throwing out the debris, further testing is done through silencers. Uncontrolled blow-outs are also very noisy but these are infrequent.

The "hot-water" or liquid-intensive geothermal field has problems of a different nature. It takes from 100 to 150 pounds of hot water (in contrast to 16 to 20 pounds of steam) to produce a kilowatt hour of electricity. The handling and disposal of these large quantities of water per unit of power cause most of the environmental problems of the "hot-water" geothermal plant.

Thermal waters carry dissolved solids ranging from a few hundred to hundreds of thousands of parts per million. The presence of these dissolved chemicals usually precludes intermingling the geothermal waters with other surface waters, and in the United States necessitates their injection into the ground.

Because of the fear of ground subsidence from the removal of large quantities of water and possible seismic effects due to reinjection, no hot-water fields have been developed in the United States. Such fears, however, are not founded on fact. Detailed studies have shown that subsidence from geothermal fields would not occur in most areas. Where it presented a potential problem it could be alleviated by reinjection, as practiced in the oil fields. Induced seismic activity relating to injection of fluids into the ground is shown to be proportional to injection pressures. Because the reinjection of geothermal fluids involves only a return of fluid to the reservoir at hydrostatic to sub-hydrostatic pressures, there is no reason to believe seismic activity would be induced.

Geothermal plants do not require a supplementary source of cooling water when using natural steam or the flashed cycle. The steam, after passing through the turbine, is condensed, piped to the cooling towers, and then recirculated to cool the condenser. By this method, the field at The Geysers produces about 20 percent more condensate than is evaporated. This surplus is then returned to the reservoir where it originated, thus prolonging the useful life of the field. A geothermal plant is the only type of thermal power plant that does not compete with other uses for our dwindling supplies of water.

The environmental impact of any power-production system is reflected in the number and complexity of the steps in the fuel and production cycle. Because geothermal power plants utilize naturally occurring steam, they need no complex steam-generating equipment or extensive mining, processing, storage, or transportation facilities, as do other thermal power plants; but, because all the power production steps are localized within the bounds of the geothermal field, it may appear that the geothermal plant has considerably more effect on the environment. As a practical matter, development of a geothermal field will displace other land uses in the area. However, after the initial construction period, most of the area within the geothermal field can return to pre-existing land-use patterns compatible with geothermal developments. An example of this is the Larderello field in Italy where development has stabilized. Most of the area occupied by the geothermal field is covered with farms, orchards, and vineyards, with the wells, steam transmission lines, and power plants occupying only a small percentage of the land.

Utilizing Geothermal Waters

Of local importance but largely overlooked on the national scene is the use of geothermal energy for direct application, such as space heating or for heat needed in industrial processes. For this purpose, waters of much lower temperature than is necessary for electric power production can be used, greatly broadening the resource base. Probably the best known example is Reykjavik, Iceland, where a large district heating system provides nearly all the space heating for this city of 85,000. Extensive use is made of geothermal waters in Hungary, where in Budapest alone 5,600 flats are supplied with natural hot waters. Some of the most imaginative uses of geothermal waters occur in New Zealand. Aside from electric power production and space heating for homes, businesses, and industries, geothermal energy is used for cooling via absorption refrigeration and for process steam in a large paper mill. In the United States, the largest utilization of natural hot water is in Klamath Falls, Oregon, where several hundred homes and numerous schools use geothermal waters for heating. Several other cities in the West make some direct use of this energy source.

Utilization of geothermal fluids for space and process heating may involve little more than the drilling of a well and circulating the fluids through a radiator in the home. In some cases, heat exchangers are used, and in others it is necessary to make minor changes in the chemistry of the waters to keep minerals from plugging the pipes. The disposal of these fluids is handled in different ways, depending upon the region and quality of the fluids; some are put directly into surface streams and some underground. Often the spent fluids are of sufficient quality to be used directly for irrigation or stock watering. If aquifer conditions are appropriate, there is no need to bring the geothermal fluids to the surface; instead downhole heat exchangers can be used and clean secondary fluids circulated to the surface installations. All of these techniques are practiced in some areas; nowhere has it been necessary to resort to complex techniques of effluent capture and disposal.

The direct use of geothermal energy has been largely unheralded because it lacks the glamour and large revenue aspects of the production of electric power. However, the total amount of energy produced for direct use exceeds that for electric power production from geothermal resources today. The direct use of geothermal fluids for space heating is particularly attractive in arctic and sub-arctic areas where winter heating is a major economic burden and where the winter high-pressure weather systems often create a pall of lingering smoke and fog from the burning of fossil fuels. There should be a major effort in those areas where geothermal resources are available to build district heating systems on the pattern of Reykjavik to lower the overall pollution and decrease the use of and dependency on fossil fuels.

Conclusion

The use of geothermal energy has a long history of successful operation. Seventy years of operating experience at Larderello and 20 years at Wairakei have shown geothermal systems to be economically and environmentally successful. It is known that geothermal energy exists in vast quantities; its resource base is second only to solar energy. But how much geothermal energy is sufficiently concentrated to be utilized economically is not known and can only be answered by serious exploration to locate and develop geothermal reservoirs. Unfortunately, delays and harassments are discouraging the exploration for geothermal energy in the United States at a time when the world most needs this clean supplemental energy to help reduce environmental degradation and offset the rapid depletion of fossil fuels.

CONVERSION OF OIL SHALE

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I am delighted to have this opportunity to discuss oil shale development prospects. While the so-called "energy crisis" has been unfolding, and it has been for many years, I have been working toward the development of this and other substitute fuels. So have many of my associates at Atlantic Richfield Company. I discovered a couple of years ago that I inherited my interest in oil shale when my mother told me that I was preceded in technical and economics investigations of the resource by my father. He looked at it before I was born but chose to return to Texas in dismay, to the conventional oil business. More recently, my ninety-year-old grandfather in Prescott, Arizona asked me what I was doing these days. He's hard of hearing, so I usually talk to him in simplistic words. So I answered that I was working on getting oil out of rocks. He reared back in his chair, looked at me suspiciously, and finally suggested, "Come on out here; we have lots of rocks."

It has taken us a long time to get around to it, but I think by now just about everybody in this country knows that the United States has an energy problem that could become a problem of frightening magnitude. After last summer's gasoline shortage, and previous fuel oil shortages which closed the schools, the discomfort of not having readily available energy sources has caused a rude awakening resulting in much verbiage and finger pointing. Finger pointing proliferates today; as you've probably noted, no less than four Congressional Committees have set out to "get the facts" regarding the fault of the oil industry.

People tend to react slowly unless faced with a crisis situation -- like the proverbial ostrich which hides its head in the sand. But with our energy deficiencies, there is no magic solution, and the problem will not go away by hiding our heads in the sand -- or by looking for scapegoats. A search for scapegoats serves only to relieve some tension -- it certainly doesn't resolve the energy problems.

Currently we are experiencing the very uncomfortable symptoms of an energy situation in which our productive capacity has fallen behind our needs. But how did we get into this predicament? What are the root causes? Perhaps this is all just a monumental hoax contrived by the big oil companies?

In a recent editorial in Outdoor America, public suspicion of government and industry is focused in the question, "What were all the energy experts doing while this 'crisis' was building up? Building it up?" Let me assure you that leaders in both industry and government have prophesied our current predicament for over a decade, but the warnings fell on deaf ears; that a notion blessed with such abundance of what we now realize to have been cheap energy to have a "crisis" was incomprehensible. But we are now victims of the peaking of domestic petroleum production that has been forecast for 10 years or longer.

To most Americans the parameters of this crisis are ill-defined, and its implications poorly understood. It is a complex problem with a myriad of interacting forces that has brought us to this unhappy, unhealthy, and, from a national security standpoint, unsafe juncture. To begin with, the basic cause of the energy problem is that there has been and continues to be a rapidly increasing demand for cheap energy; as a nation we've been energy gluttons, to the point where our demand seems to double about every 16 years. Some of it, admittedly, is wasteful demand, but is, nevertheless, demand. We have on one hand a never-ending capacity to dream up new ways of consuming energy and on the other, the fact that our efforts to develop energy supplies are falling short of expectations. Please note that I have not said that we are running out of energy, just that we are running out of cheap energy; the old law of supply and demand has finally caught us in its inescapable grasp.

The excruciating pressure of demand on a global scale is illuminated by the fact that the increase in world energy use in the 1960's was equal to that of the previous 35 years, from 1925 to 1960. With more economic opportunity and a higher standard of living for the expanding world population, we can expect a continued high rate of growth in utilization of energy. These factors are inseparable. The shortages of energy implied here will hurt economic activity and personal income much more seriously than will higher priced energy -- reflecting the real cost of energy -- required to restore some equilibrium in our present system.

The forces responsible for current energy problems hove been at work for a long time and Federal concern about long-term energy supplies dates back to 1954 when a Cabinet Committee was created to study the problem. Although the problems ore complex, they are not unsolvable. Bear in mind, however, that the wrong energy move now could make present-day shortages pale in comparison to those ahead of us.

Let me, first of all, trace the root causes of our present dilemma in the U. S. In a nutshell they include the following:

1. Gas Price Regulation. In the 1950's, the wellhead price of gas was fixed at a level so low that it killed any motivation for companies to explore for new gas fields. The price was not allowed to reach a competitive level. This has curbed exploration, lead to artificial stimulation of consumption, and it probably has acted to delay development of technologies for coal gasification.

2. Low Cost of Foreign Oil. The availability of low-cost fuel from foreign sources made it easier to import oil than to risk the expenditures of a one-in-fifty gamble on exploring for and drilling new oil wells domestically. "Cheap" foreign oil is now a myth -- the Arabs have us over a barrel, to use a bad pun, and we find ourselves facing rapidly rising prices on foreign crude with limited capacity for domestic crude production. Presently, imported crude oil is considerably higher priced than domestic crude oil. Balance of payments, national security, volatile political climates in the Middle East, and competition for Middle East oil by other big industrial powers, further compound this area of concern.

3. Environmental Concern. We have entered what some call the "environmental decade." The building pressure to burn clean fuel has not been accompanied by the technology necessary. Public interest has focused on the protection and enhancement of the environment as its energy sources are developed, regardless of costs or consequences. This emphasis on environmental protection has impaired the development of coal as an energy source, delayed construction of nuclear power plants, and delayed availability of oil and gas from the Outer Continental Shelf and Alaska. I do not mean to object to environmental concern; I applaud it. Nevertheless it is fact that it contributes in an important way to energy shortages.

4. Nuclear Delays. Nuclear power, which was to be our savior in the 60's has not come on stream nearly as soon as we'd anticipated. Public concern over radioactivity, delays in developing the breeder reactor, questions over thermal pollution, and licensing red tape have all contributed to nuclear power falling far short of its earlier promise.

These facts are complicated further by the projections that between now and 1985, our energy requirements will about double, while our present resources of oil, gas, coal, and nuclear power will not be developed in sufficient time to meet these growing requirements. So, the problem comes quickly into focus: How can we meet this demand that has skyrocketed far beyond anyone's expectations?

The massive scale of our energy base, as well as the complex time and economic relationships, exclude simplistic answers. Our current energy posture did not emerge overnight. Actions to overcome these problems will require informed public decisions and responsive mechanisms within the Federal Government. Unfortunately, the long lead time involved in major changes of demand and supply means that energy problems will become worse before any progress can be made toward good long-term solutions.

As I see it, the nation essentially has three basic options: First, we could rely on increased imports of oil and gas from overseas to meet our requirements. Recent trends have been toward increased imports. We cannot forget, however, the terribly important point that increasing our dependence upon foreign fuel sources weakens our national security, as already evidenced by the Middle East conflict, and it provokes a burdensome deficit in our balance of trade in fuels. Energy is an international commodity, and emerging international energy trends are cause for increasing concern. For example: 1) There are shifting trends in the flow of international payments as investment, trade, and profit patterns change. 2) There is growing potential for use of energy as an economic and political weapon. 3) And there is the constantly changing relationship between U.S. energy companies and government, both foreign and our own. The ramifications of this option are fraught with danger and not what I would consider viable.

Second, we could reduce the growth in energy demand through imposed restrictions or more efficient use of energy. Allocation of fuel, which in a broad sense is a form of rationing, provides a partial answer. But let me stress that any allocation program, whether voluntary or mandatory in concept, is merely a palliative, not a cure. It treats only the symptoms, not the disease. It would only insure that the shortages are distributed equitably and does not address the more basic need to restore a proper balance between demand and supply.

Imposed restrictions would necessarily alter lifestyles and adversely affect employment, economic growth, and freedom of consumer choice. This course of action is probably an imperative one, but it will certainly not be a pleasant one.

To some sectors of society, more efficient use of energy, or energy conservation appears a panacea. It is certainly a desirable action, and some improvement is likely as energy prices spiral to reflect the cost of producing clean and environmentally safe energy. There are still inherent limitations on the extent of the improvements that can be accomplished even here.

Third, we can accelerate the development of our domestic energy resources. Expert scientific studies indicate that we have the necessary domestic resources to significantly reduce energy imports in the 1980's and beyond. In fact, most foreign nations would give their collective right arms to have such domestic resources. Exploration, recovery, and distribution have been stagnant only because of a lethal combination of negative economics and positive ecological pressures.

Basic economic theory proves that low rate of return on investments activates the easily understood phenomena of less incentive, less exploration, less discovery, and less reserves. To attract the vast capital requirements to develop our indigenous resources, we will need higher prices and appropriate national energy policies.

The Chinese ideogram for "crisis" is a combination of the symbols for "danger" and "opportunity." Attendant to the energy crisis we have that very mix and are in the uneasy posture of trying to understand both. One of our more notable "opportunities" lies in the country's largely untapped resource of synthetic fuels. Shale oil and synthetic petroleum derived from coal can be refined into a complete range of normal petroleum products and represent one of the best long-range bets to help solve the energy crisis. The United States contains half the known coal resources of the world, and those can fuel the country for as much as two hundred years.

Now, to speak more specifically to the questions of oil shale and its role in achieving domestic self-sufficiency. I should explain at the start that oil shale isn't really shale and doesn't really contain oil. It did, however, have a beginning much like conventional petroleum, and as such, oil shale is hardly a modern phenomenon.

Fifty million years ago in ancient Lake Uinta, now a part of the Colorado River Valley in the Rocky Mountains, tremendous amounts of organic material were deposited. Over the aeons, these deposits solidified into what is considered to be the richest deposit of oil shale in the world. It is a sedimentary rock containing organic matter called kerogen which yields substantial amounts of synthetic oil and hydrocarbon gas when heated. Although oil shale did have the same beginning as conventional petroleum, when organic material was deposited in large, ancient lakes, these deposits were not subjected to the heat and pressure necessary to form petroleum. Instead, the organic material was transformed into a solid hydrocarbon and locked in a marlstone matrix. When the kerogen is heated to a temperature of approximately 900° F, it decomposes to yield hydrocarbon gases and liquids.

Oil shale is found throughout the world, in every continent, and in at least 30 states of our nation. Reserves of oil shale are expressed in terms of barrels of oil recoverable per ton of rock by a standard laboratory analytical technique called "Fischer Assay." The world's largest reserves with the potential for commercial development are found in the Green River Formation in Colorado, Utah, and Wyoming over an area of about 17,000 square miles. The U. S. Geological Survey has estimated that the total oil shale reserves of the Green River Formation are more than 600 billion barrels of oil in deposits at least 10 feet thick, averaging 25 or more gallons of oil per ton of oil shale. The Department of the Interior has also estimated that 80 billion barrels of this reserve are recoverable by modern mining methods. This total is approximately twice the present domestic crude oil reserves exclusive of Alaska. To put this in some perspective, the United States, since the Civil War, has produced about 1 billion barrels of petroleum.

The Piceance Creek Basin, which ranges over 1,250 square miles in Garfield and Rio Blanco Counties in Western Colorado, is the richest single area of recoverable oil shale in the United States. This area is in semi-arid Western Colorado, where the rugged terrain consists of plateaus cut by intermittent streams and creeks to form canyons and valleys. The streams drain north into the White River and south into the Colorado River.

Throughout the last 50 years and particularly the last 10 years, many millions of dollars have been expended to develop the technology of extracting oil from oil shale. In fact, one could state that the industry has been on the threshold for the last 10 years, and only the high cost of production associated with oil shale has kept it from being a commercial source of petroleum crude or energy. Recent changes in energy economics, coupled with the current energy crisis, have made it feasible and advisable to create an oil shale industry capable of supplying significant quantities of petroleum crude to this country.

Oil shale alone is not a panacea to our crying need for petroleum. Despite the vastness of the reserves and the enormous energy potential contained in the rock, the logistics and costs associated with extracting this oil are also enormous and perhaps the most outstanding challenge the petroleum industry has faced since World War II.

Enormous quantities of rock must be mined, crushed, and heated in order to extract the oil. More than a ton of waste material in the form of finely divided rock must be disposed of for every barrel of oil produced. All of this, of course, must be done in a manner which is environmentally acceptable and with assurances that the environmental impact of such an industry will be minimal, both in a short range and long range analysis.

However, the oil is there. We know how to get it. We know how to get it in an environmentally acceptable manner.

It is appropriate to discuss for a moment who the "we" are that possess this expertise within the area of oil shale. It is an exclusive fraternity that has required many millions of dollars of developmental expenditures and effort as an initiation fee. Having been responsible for that expenditure, I am in a position to state in an unqualified manner that the "we" at present is Colony Development Operation. We presently stand closer to the threshold of commercial development than any other organization. Colony has at hand a fully developed commercially viable process for extracting oil from oil shale. We are the leader in developing the industry and have arrived at this position only as the result of great effort.

Let me review briefly the history of development which has occurred in oil shale technology within the United States.

Since 1917, there has been a variety of attempts to develop or define processes for extracting shale oil from shale. As many as 200 oil shale companies have been founded during this period of time. Many were simply stock companies; however, several firms actually built equipment, some of which produced several barrels of oil per day. Very few of the companies survived, since the cost of producing oil from shale was far greater than the value of conventional crude oil.

Despite the fact that the economics did not warrant commercial production of shale oil, many large companies, primarily petroleum companies, invested large sums of money in attempts to develop extraction processes so they might have an "on the shelf" process ready for application when the economics warranted.

Some of the outstanding efforts which occurred are: From 1947 to 1956 the Bureau of Mines operated experimental facilities at Anvil Points West of Rifle, Colorado. This program investigated the feasibility of the gas combustion retort.

Union Oil Company operated a pilot plant north of Grand Valley, Colorado during the 1950's, utilizing an interesting modification of the gas combustion retort. Union is again at work on their process and they fully expect to successfully complete development of it.

The Colony group began their operations in the 1960's, and from 1967 to 1972 was the only active group within the area. The Colony program was directed toward the demonstration of the commercial feasibility of a proprietary process known as the TOSCO II Process. This objective was achieved and the TOSCO II Process stands alone as the only oil shale retorting process which has been demonstrated on a large scale within the United States as a commercially viable process.

This brings us back to Colony - who are we and what are we doing?

The original Colony group consisted of Sohio, Cleveland-Cliffs Iron Company, and The Oil Shale Corporation (TOSCO). In 1969 Atlantic Richfield purchased a 30 percent interest in Colony and became operator of a $17 million extension of the original project. Since September 1971 the project has been conducted by Atlantic Richfield Company as operator, and an additional $7 million has been expended. This effort has placed Colony in an unqualified position of leadership within the oil shale industry.

From Colony's vantage point, we see there is only one direction to go, and that is forward. Otherwise, the individuals who have become expert in this field, the accurate engineering information which has been assembled, and the dynamic motivation present within this difficult technical area, may be lost to the country.

As a company, we strongly feel our obligations of stewardship towards this charge and believe wholeheartedly that to shelve the information and expertise available to us now and abdicate the responsibility of utilizing this vast resource of energy would be untenable. We view the time as right for the industry and the need for this resource as obvious and critical.

What is the potential for oil shale with regard to the nation's petroleum needs? It's a new industry and there are several questions remaining to be answered. These are questions which can only be answered at the commercial scale. Persons advising that we place a hold on the creation of this industry so that we may further explore at the bench scale or pilot plant level, do this country a disservice. None of the significant remaining questions can be resolved without that first giant step, "The First Commercial Oil Shale Plant." We are dedicated to this philosophy and this is why we propose to build a 50,000 barrel per day plant as soon as feasible.

Since it is a new industry, it is unlikely that there will be a rapid proliferation of commercial plants. The results of the first plant will be observed and evaluated and the speed of the industry's growth will be paced in accordance with the success of the first plant.

The government's forecast of a 1 million barrel per day industry is reasonable. The oil shale industry can be functioning at this level, I believe, within approximately 10 to 15 years after the first plant comes on stream.

While a certain amount of engineering and management judgment is involved in a decision of this magnitude, Colony has based their decisions and forecasts on the experience gleaned over approximately 10 years of developmental experience.

Colony's development activities have been centered in the operation of the largest prototype oil shale plant within this country. This plant, located approximately 15 miles north of Grand Valley on the Western Slope, processed approximately 1,000 tons of oil shale per day, and has produced as much as 750 barrels of oil per day.

Our research laboratories have examined a variety of refining processes in order to determine the best way for refining raw shale-oil crude into acceptable conventional petroleum products. We have explored, at great cost, all aspects of mining within commercial-size, underground room and pillar mines.

A plant combining this mining, retorting, and pre-refining expertise is now capable of producing a full range fuel oil acceptable under the most stringent of environmental constraints.

The quality of our natural environment is on all of our minds these days. To this end, Colony is expending a great deal of time and huge sums of money on how to deal with the reparation and preservation of land that we might utilize. Major areas of concern that have been studied include air, water, processed shale disposal, revegetation of processed shale, wildlife impacts, and a complete ecological inventory and analysis.

We have learned how to safely dispose of large quantities of processed or waste shale in an environmentally acceptable manner. We have learned what the problems of air pollutants are, and how to control them. We have studied and learned how to revegetate disposal piles and restore terrain to its original appearance.

Colony is convinced that the next step should be commercialization. Our resources are dedicated to this. For until the first plant is built, no one can say with precision what the ultimate long-range potential of these millions upon millions of barrels of oil locked within the Piceance Basin will be.

Since the industry is not yet off the ground, it is difficult to predict its future. However, I will offer an educated guess as to the supply potential of this resource. I would compare it at present to the Prudhoe Bay oil field on the North Slope of Alaska. In terms of gross reserves, oil shale contains at least ten times as much recoverable oil as Prudhoe. The Department of Interior hopes to see an industry producing at least one million barrels per day and perhaps as much as two million barrels by 1990. Technology improvements could increase this -- such concepts as the use of saline water to minimize fresh water consumption are needed.

In order for the United States to approach the President's stated goal of energy self-sufficiency (and note that our present rate of consumption is about 18 million barrels of oil a day, while domestic production is declining and is less than 12 million barrels per day), we must develop all of our obvious liquid-fuel resources. The most obvious and therefore crucial available liquid-fuel resources are the North Slope of Alaska, our essentially unexplored Outer Continental Shelf, and oil shale.

In conclusion, let me say this. All periods of deep change have required us to adjust. The kind of changes that are almost certainly in store for us will force alteration in our habits, attitudes, and values. There is a highly visible attitude in the country today regarding protection of the environment from possible or potential damage. There is concern on the East Coast about offshore oil well drilling on the potentially very important Outer Continental Shelf. There is concern on the Atlantic Seaboard regarding supertanker unloading facilities. There is concern in Southern California about drilling in the potentially prolific Santa Barbara Channel. Similar concerns abound in Colorado regarding oil shale development.

Yet, there is still another dimension to this discussion. We seem to be caught in a potential conflict between social needs and environmental needs. This challenge of dealing with man's total environment -- the way that we all must live -- is going to be tough, and if, in our quest for preservation of the air and water and land, we relegate man's needs, such as the quest for adequate jobs, a reasonable standard of living, sufficient housing, personal safety, education, and health care, to a position subordinate to preservation of a natural area, we most certainly fail in our responsibility to the people.

THE SYNTHANE COAL-TO-GAS PROCESS

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Introduction

The Synthane Process is a system developed by the Department of the Interior's Bureau of Mines for converting coal to synthetic natural gas. That such a system would be a valuable addition to this country's fuel complex is evidenced by two developments: The apparent decline in American natural-gas reserves, and the growing public demand for fuels, such as natural gas, that do not pollute the environment.

A number of research organizations are studying gasification; at present, however, the only pressure system being operated commercially is the Lurgi gasifier. The Synthane Process has several advantages over the Lurgi gasifier, chief among them the fact that the Synthane Process can be used to gasify any type of coal -- even the so-called coking varieties. These coals are unsuitable for most gasifying systems, including the Lurgi, because of their tendency, at high temperature, to swell up and plug the gasifying unit; yet such coals make up the bulk of all bituminous coals in the United States, including large deposits east of the Mississippi, where demand for supplemental natural gas is greatest. The Synthane Process, then, with its pretreatment approach to gasification of caking coals, opens up the possibility of a plentiful, environmentally acceptable fuel supplement in a region where it is badly needed.

Headquarters for Bureau of Mines gasification research is the Pittsburgh Energy Research Center, located in the Pittsburgh suburb of Bruceton. Gasification research recently has been aimed at obtaining engineering data for the Lummus Company, a design firm that the Bureau has commissioned to prepare designs for a prototype Synthane plant. The plant will have a capacity of 75 tons of coal per day, and will be located adjacent to present Bureau research facilities at Bruceton. The plant is expected to be operating by mid-1974.

This report summarizes past and present Bureau research on the process. The four main operating steps of the process--pretreatment, gasification, purification, and methanation (Figure 1)--are discussed, plus the planned prototype plant and the possible effects of the process on the environment.

Pretreatment

A key aspect of the gasification research at Bruceton involved pretreatment. Coals with a free-swelling index of two or higher must be pretreated if they are to be used in a fixed or fluid-bed gasifier. It is possible to pretreat coals in a fixed bed, in a fluid bed, in free-fall, or by entrainment. In the Synthane Process, the pretreating and gasification stages are combined, a benefit not found in other systems. The gases formed during pretreatment contain methane, carbon monoxide, and hydrogen. These gases enter the gasification reactor and become part of the final product, adding to the overall methane recovery of the system.

Development work was started in 1961 on methods of pretreating caking coals in a fluid bed using coals sized to minus 10 mesh. Tests demonstrated it was possible to pretreat any caking coal by using the proper concentration of oxygen in the fluidizing gas, temperatures of about 750° F, and sufficient residence time (Forney and others, 1964-a, 1964-b).

One method of increasing the throughput of cool in the fluid-bed gasifier would be to increase the cool size. Tests mode with minus 20-mesh coal showed that this coorser cool could not be pretreated in a free-fall pretreoter shown in Figure 1. The larger coal, however, could be handled in a fluid-bed pretreater without difficulty. Tests mode in the gasifier with the minus 20-mesh cool pretreated in a fluid-bed reactor showed that this was a satisfactory method of operation. Thus, it was possible to increase the maximum superficial gas velocity from 0.2 to 0.4 ft/sec without increasing significantly the corry-over of fines from the reactor. As a result of such tests, we hove increased the overage particle diameter of the cool from 95 microns to 240 microns.

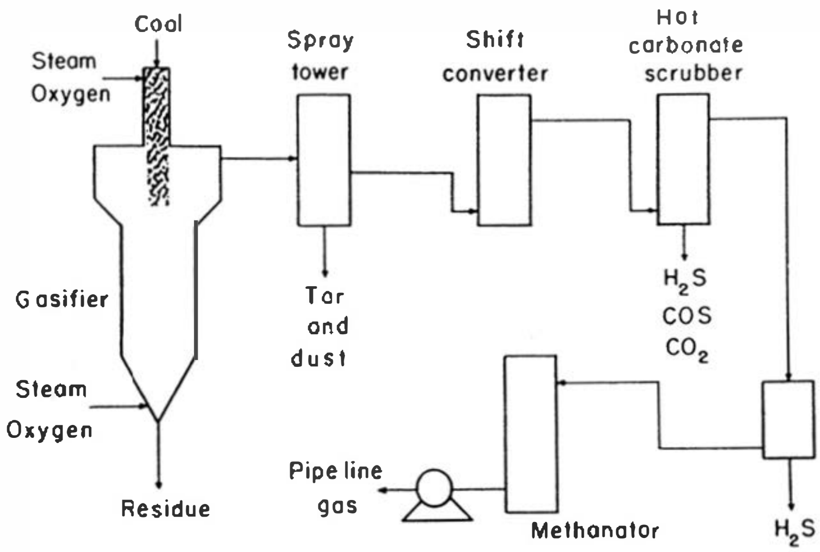

Figure 1. Overoll synthone process.

Gasification

The present gasifier at Bruceton is shown in Figure 2. It is o 4-inch diameter tube inside o 10-inch diameter shell. The outer shell (304 SS) is copoble of containing the 40-otmosphere pressure, ond the inner tube (310 SS) is copoble of containing the 1,800-1,900°F temperature.

The coal is fed from the cool hopper to the pretreater where the coking quality of the coal is destroyed by treatment with oxygen plus steam at 750°F. In the gasifier the cool posses through o carbonizing zone, then to the fluid-bed gasifier which operates ot 1,800°F, where the cool is fluidized ond gasified with steam ond oxygen. The char is extracted from the gasifier by a screw ond posses to a pressure hopper. The gases pass through a series of filters and condensers to remove dust, tors, ond waters. The dry gas is analyzed by a chromatograph ond measured by a meter (Forney ond others, 1967, 1970).

Purification

Gasifier effluent must be purified prior to final conversion to methane. This is accomplished in several steps: first, the char is removed by a cyclone and used for steam generation. Then cool tors ore condensed in a water-wash tower, which also removes any char entrained from the cyclone. After separation from the wash water the tor may be burned to raise process steam or returned to the gasifier.

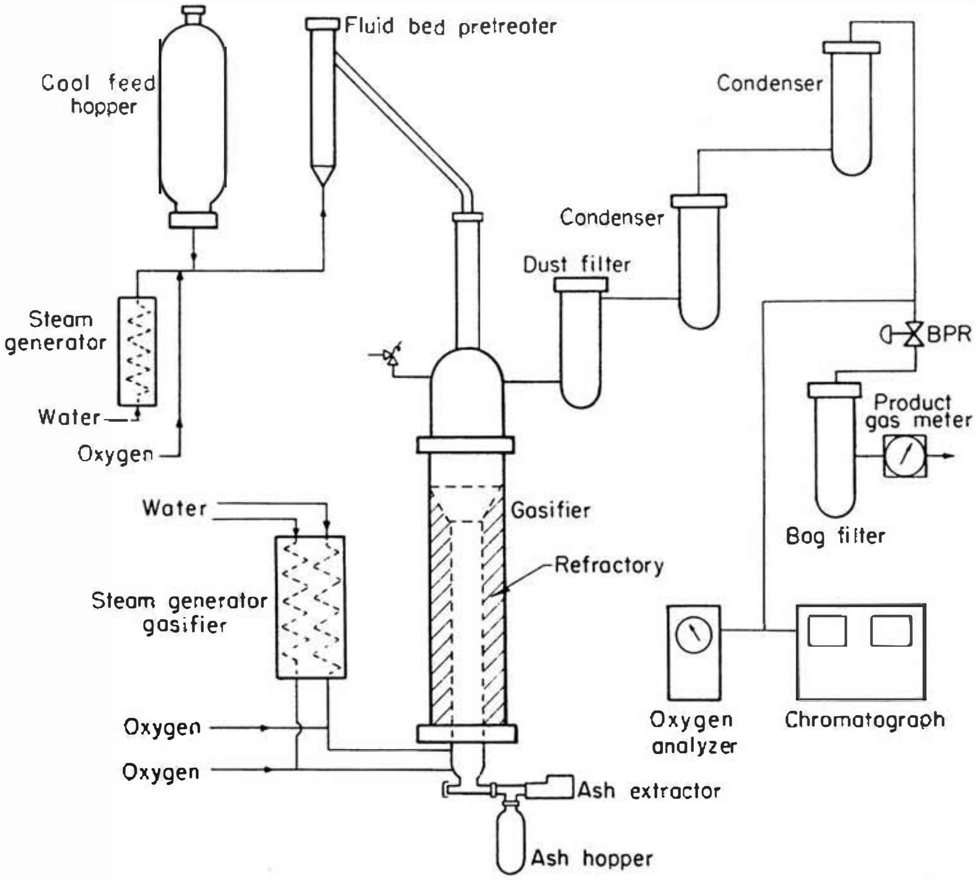

Figure 2. Bruceton experimental gasifier system.

Selectively acid gases are removed with a hot potassium carbonate solution. This method, developed by the Bureau of Mines about 14 years ago and now used extensively in commercial operations (Field and others, 1962), can reduce the CO_2 and sulfur content of the gas to 2 volume percent and 40 ppm, respectively. From the regeneration of the potassium carbonate solution, an H_2S-rich gas stream is evolved that can be converted to elemental sulfur. Final traces of sulfur are removed from the purified gas before methanation by passing it through iron oxide and activated charcoal or, as an alternate, zinc oxide. All of these steps are considered to be commercially proven and can be adopted to the Synthane Process without further experimentation. However, other purification routes that may have economic or operational advantages are being considered.

Methanation

The gas that emerges from the Synthane gasifier after the water-gas shift and purification steps contains a considerable amount of $CO + H_2$ which must be catalytically converted to methane in order to increase the heating value of the gas (from about 560 Btu/scf to over 900 Btu/scf), and to reduce the CO content of the product gas to less than 0.1 percent. The basic methonotion reaction is as follows:

$$3\ H_2 + CO \rightarrow CH_4 + H_2O + heat$$

The reaction is highly exothermic; about 65 Btu/scf of H_2 + CO converted. A suitable catalyst is needed to make the selective methane reaction proceed at o practical rote. Means must also be provided for removing the lorge quantity of reaction heat and for maintaining the desired reaction temperature. If removal of reaction heat is not adequate, excessive catalyst temperatures result, carbon con form and plug the reactor, and catalyst activity is greatly reduced. Efficient heat removal, therefore, is o critical requirement of the methonotion reactor.

The Bureau has developed two operable methonotion systems that ore being considered for the Synthone Process: the hot-gas recycle (HGR) (Forney and others, 1965), and the tube-wall reactor (TWR) (Haynes and others, 1970) systems. Both use roney nickel catalyst flame-sprayed onto plates or tubes. The HGR utilizes the sensible heat capacity of the recycle gas to remove the exothermic heat of reaction from the catalyst. The TWR removes the heat of reaction by means of conduction through the catalyst-coated tubes, which contain boiling Dowtherm.*

Temperature control in the HGR pilot plant tests has been excellent. The use of nickel-coated steel plates, assembled in parallel modules, results in o reactor pressure drop only o fraction of that encountered in fixed-bed reactors packed with granular catalyst. Because the pressure drop in the HGR is less than in conventional reactors, compression costs of recycling gas ore likewise reduced. Pilot plant tests of longer duration ore needed to determine the life expectancy of the HGR catalyst system. Extended on-stream time may be achieved by taking advantage of the flexibility of the HGR system. Process parameters such as reaction temperature, temperature gradient across the catalyst, volume of recycle gas to fresh feed gas, and concentration of CO and water vapor may be adjusted as needed.

The TWR methonotion system is the design chosen for initial prototype plant operations because long-term catalyst life of over 2,800 hours has been successfully demonstrated. The pilot plant TWR also has yielded very large amounts of synthetic pipeline gas per unit weight of catalyst--240,000 scf per pound of catalyst. Yields for the small laboratory TWR were even higher.

The product gases in pilot plant tests of both the TWR and HGR systems contained residual carbon monoxide concentrations of 0.5 to 2.0 percent, depending upon operating conditions and age of catalyst. The acceptable level for pipeline gas is 0.1 percent. This standard could be met if the reactors were operated at below-capacity loads. A better alternative would be to run the reactors at full load and odd o second stage methonotion reactor to convert the excess CO to methane. Tests ot Bruceton hove shown that o second stage methonotion reactor, packed with commercially available granular methonotion catalyst, con convert the residual CO to methane and reduce the CO content of the product gas to less than 0.1 percent. This was achieved ot feed gas space velocities of 5000 scfh per cubic foot of catalyst volume, making the second stage reactor relatively small and inexpensive compared with the first stage reactor. When CO and CO_2 content in the feed gas is kept below 2 percent, and the gas is sulfur-free, the catalyst life in the second stage reactor is expected to be 2 to 5 years.

Pollution Control

Gasification offers o means of converting o "dirty" fuel to o clean fuel. However, large-scale gasification itself could become o significant source of oir ond water pollution. A 250-million scfd plant, for example, would discharge 2 to 3 million gallons of water containing as much as 1 million pounds of impurities every day--quantities roughly equal to the emission from the nation's largest coking operation. Similarly, the smoke from o 250-million scfd plant could contain as much sulfur as that from o 250-megowott power plant, assuming that both were burning o 3 percent sulfur cool. A number of pollution control possibilities ore therefore being explored with regard to the Synthone Process.

* Use of trade names is mode for clarification only and does not imply endorsement by the Bureau of Mines.

Condensate water is the most serious potential source of water pollution in the Synthane Process. Condensate water derives from the unused steam fed to the gasifier; for every ton of coal gasified, 0.4 to 0.6 ton of water will be recovered. The condensate contains about 95 percent water, the balance being significant quantities of ammonia and phenols, plus traces of quinoline, naphthalene, pyridine, and compounds such as dissolved gaseous sulfur.

The ideal solution for handling gasification condensate would be to convert it to steam and recycle it back to the gasifier. One question yet to be resolved is the degree of cleanup required to make the by-product water suitable for steam generation. Water formed during the methanation step, on the other hand, should require little purification before discharge or recycle to the steam generator.

Prototype Plant

A contract with the Lummus Company for the design of a Synthane prototype plant capable of gasifying 75 tons per day of coal or lignite at 1,000 psig has been completed. The prototype gasifier will be 3 feet (inside diameter) by about 90 feet high. In the gasifier there will be a free-fall section, a fluid-bed carbonization section, a fluid-bed gasification section, and a fluid-bed char cooler. The pretreater will be a separate fluid-bed unit which will feed non-coking coal into the top of the gasifier, similar in design to the pretreater shown in Figure 2 (the present pilot-plant gasifier at Bruceton). This separate fluid-bed pretreater is designed to handle minus 20-mesh coal. The raw coal, steam, and oxygen will be fed into the bottom of the pretreater, which will be operated at 400°C (750°F). The pretreated coal, tars, and gases will be fed into the top of the gasifier. Energy balances show that the overall system is in balance when 65 percent of the carbon in the coal is gasified, and the unconverted portion is used to generate steam for the plant.

The methanator designs will be similar to those used in the Bruceton laboratories. Since the hot gas recycle and the tubewall reactor systems appear to be well suited to the methanation reaction, both will be included in the prototype plant. The tube wall design will incorporate the use of 2-inch diameter tubes, with the catalyst flame-sprayed on the inside rather than on the outside. This technique was developed recently at Bruceton, and the change will make the TWR system more practical as it will be easier to replace the catalyst on the tubes.

The other major process steps, the water shift gas converter and the synthesis gas purification, are not considered to present design problems. Units to carry out these processes are available commercially.

The chars, tars, gases, and waters will be incinerated, so there should be no pollution problem in the prototype plant. Some of the byproduct water will be fed into the gasifier to generate steam.

Summary

The Synthane Process has proven operable in a pilot plant and scale-up appears feasible. The two most critical steps in the process are the gasification and the methanation.

Gasification by the Synthane Process offers the promise of (a) broad flexibility in type of coal feed, (b) high throughput rate of coal and commensurate low initial cost, (c) high methane content of gasifier product, and (d) low oxygen consumption.

Methanation by the Synthane Process offers the promise of (a) high throughputs (up to 120 scfh feed gas per sq ft of catalyst surface), (b) long catalyst life (more than 4 months operation), and (c) high yields of product gas (more than 240,000 scf of high-Btu gas per lb of catalyst).

Present plans are to proceed to a prototype plant capable of handling 75 tons of coal per day. Construction is planned for fiscal year 1973 from the design made by Lummus Company.

References

Field, J. H., Benson, H. E., Johnson, G. E., Tosh, J. S., and Forney, A. J., 1962, Pilot-plant studies of the hot-carbonate process for removing corbon dioxide and hydrogen sulfide: U.S. Bur. Mines Bull. 597, 44 p.

Forney, A. J., Demski, R. J., Bienstock, D., and Field, J. H., 1965, Recent catalyst developments in hot-gas-recycle process: U.S. Bur. Mines R. I. 6609, 32 p.

Forney, A. J., Gasior, S. J., Kenny, R. F., and Haynes, W. P., 1970, Steam-oxygen gasification of various U.S. cools: Presented Second Intl. Fluid-bed Combustion Conf., Hueston Woods State Park, Ohio, October.

Forney, A. J., Kenny, R. F., Gasior, S. J., and Field, J. H., 1964-a, Destruction of caking properties of coal by pretreatment in a fluidized bed: Indus. Eng. Chem. Prod. Res. and Develop., v. 3, no. 1, p. 48-53, March.

_____, 1964-b, The production of non-ogglomeroting char from coking cool in a continuous fluid-bed reactor: American Chemistry Society, Division of Fuel Chemistry, Preprints, v. 8, no. 3, p. 1-9, August-Sept.

_____, 1967, Fluid-bed gasification of pretreated Pittsburgh seam cools: Advances in Chemistry, Am. Chem. Soc., v. 69, p. 128-140.

Haynes, W. P., Elliott, J. J., Youngblood, A. J., and Forney, A. J., 1970, Operation of a sprayed roney nickel tube-wall reactor for production of o high-Btu gas: Am. Chem. Soc., Div. of Fuel Chemistry Symposium, Preprints, v. 14, no. 4, p. 26-48, Sept.