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University of Missouri--Rolla

Extension Division

ENERGY RESOURCES AND MANAGEMENT

edited by

JOSEPH T. ZUNG

DEPARTMENT OF CHEMISTRY

UNIVERSITY OF MISSOURI - ROLLA

1974

UMR EXTENSION DIVISION

ENERGY RESOURCES AND MANAGEMENT

BASED ON THE FIRST UMR-MEC CONFERENCE ON ENERGY RESOURCES HELD AT ROLLA, MISSOURI, APRIL 24-26, 1974 ON THE OCCASION OF THE DEDICATION OF THE NEW CHEMISTRY AND CHEMICAL ENGINEERING BUILDING

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JOSEPH T. ZUNG

DEPARTMENT OF CHEMISTRY
UNIVERSITY OF MISSOURI-ROLLA

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April 24-26, 1974

University of Missouri - Rolla

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Conference Chairman:	Dr. Bill L. Atchley, Chairman Governor's Missouri Energy Council (MEC)
Program Chairman:	Dr. Joseph T. Zung, Professor of Chemistry University of Missouri - Rolla

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PREFACE

This book is a collection of the technical papers presented at the First UMR-MEC Conference on Energy Resources held at Rolla, Missouri April 24-26, 1974. The conference was organized jointly by the Missouri Energy Council (MEC) and the faculty of the University of Missouri-Rolla (UMR) in conjunction with the dedication of the new Chemistry and Chemical Engineering building. It was intended to provide the public with some basic information regarding the energy resources and the new methods of conserving our precious and increasingly scarce supply of energy.

The energy crisis is fundamentally a technological problem and the only source of workable answers to this problem must come from new advances in research for new sources of energy and new methods for energy management and conservation. At present, we are now exploiting many of the benefits of science and engineering to alleviate the energy crisis: nuclear power plants with improved effectiveness, more sophisticated systems-control methods to improve reliability of electric power, etc. In the future, there remains a huge responsibility for the scientist and the engineer to do all he can to find new ways of finding, converting, delivering and using energy more efficiently.

The message delivered by various authors of this book clearly emphasizes the key role played by the scientist and the engineer in finding potential technological solutions to the present energy crisis:

- To find new kind of fuels, new energy resources not now being used, such as nuclear fusion, solar energy, tidal energy, geothermal energy.
- To find enlarged sources of present fuels and improved ways to locate and extract them.
- To improve on presently available fuels, such as cleaner oil, cleaner coal and more effective means of enriching uranium.
- To improve energy conversion techniques for higher efficiency, less waste, and fewer environmental detrimental impacts.
- To improve transmission and power delivery systems for better efficiency and safety.
- To improve efficiency in energy useage, more efficient engines, more effective use of waste heat.

I am sure that the papers presented here will not help us solve all of our energy problems, but at least they will inform the reader on many aspects of energy resources and conservation. From the disscusions of this Conference, a gigantic body of information has been collected. On this information, we can now base our assessment not only of the natural resources of the nation and the earth, but also of the likely future demands on them and of their deeper societal implications. Through a full and close cooperation between the academic community, the industries, and the State and Federal Government, we must continue to learn about what we have, how to estimate it, and how to manage it in the best interests of the nation.

The role of the academic community is mainly in education and research. In the field of education, through courses and degree programs, the university must be concerned with the education of the general public on the various effective measures for conserving our energy resources. It must also educate people to understand the conflicting aspects of energy supplies and the quality of our environment, to convince them that we must continually match our needs and desires for additional energy with our ecological hopes and dreams. In its educational role, the academic community must also strive to train competent energy experts, scientists, engineers, sociologists, economists, and even politicians, well versed in the intricate complexities of the energy field. In the research arena, the academic institutions must be fully committed to carry out basic research in all fields of energy resources and conservation. This research program may be carried out under existing structure of the academic institutions or be centralized in a more or less autonomous Center for Energy Research and Development.

On the national level, we need a firm set of guidelines set up through a high-level group of broadly qualified specialists. These guidelines should be sanctioned by Congress and Federal Government as our National Energy Policy.

On the international level, since the conditions affecting energy resources are constantly changing, thus affecting both national and international welfare, we need to set up an international review and warning system to monitor these changes in such a way that crises of supply or environmental degradation can be foreseen and avoided.

The editor

INTRODUCTORY REMARKS

Joseph T. Zung
Department of Chemistry, UMR

It is a grave concern for all of us to organize our national resources to meet future energy needs. We are at the height of the energy crisis and it is very appropriate for us to gather together here to share our views and experience in dealing with the present crisis and in planning for the future.

I think that the chief reason for the current energy bind is the total lack of a consistent national energy policy. Concern has been voiced, studies have been made, and recommendations have appeared from most of the interested groups in the nation, but there is still no policy for solving the problem. Perhaps the reason for the lack of a consistent, operational policy is a reluctance to recognize that our "inexhaustible" fuel resources are becoming exhausted.

The "Federal Power Act" adopted in the 1930's clearly set the goal "to assure an abundant supply of electric energy throughout the United States with the greatest possible economy". Thus we grew to accept cheap and abundant electric energy. In the 1970's, however, the "cheap and abundant" philosophy has clearly run its course. The goal of any new National Energy Policy should be something closer to adequate, reliable supplies of energy, produced with due concern for a need to protect the environment and conserve energy resources. This policy, in order to be viable, must be designed so as to encourage optimum development of all potential energy resources, to meet our growing energy needs on a sound economic basis, in a manner that brings energy and the environment into an effective partnership for the future.

Two essential parts of a valid national policy are a consistent and equitable method of allocating energy resources and a firm conservation program. We have organized this Conference on that basis. In the first part, we have grouped together the technical papers dealing with a vast array of new and old resources, from coal to solar energy. In part II, various authors from both industries and the academic community discuss their findings in managing and conserving our energy resources.

One of the most challenging problem today is how to allocate manpower and resources required to develop a new energy industry. The most important resource is capital. We need a huge amount of capital to develop to their full potential the energy resources readily available, such as coal, oil, and nuclear energy. We also need a still larger capital to develop new sources of energy, such as geothermal, solar, wind, tidal, fusion, etc.. But there isn't enough available capital to permit an easy transition to this new energy era. Allocating capital specifically for solution of the present energy problem will mean withdrawing capital from other areas. The decision will not be very easy. Yet this whole nation must sooner or later face it. Let us hope that we will make this decision wisely and with determination, not only to avoid further resource shortages and environmental catastrophe, but equally to achieve maximum social well being and international harmony in the uses of energy resources.

Another complementary facet of our energy program is energy conservation, which is the topic of Part II of this Conference. The authors of these sessions will share with us new methods of energy conservation and management adopted by various industries and manufacturers. They will support our concern for preserving both our natural energy resources and our beautiful environment.

Energy conservation at this present time is probably a more important issue than the development of new energy resources. It helps ease our immediate supply problems, As stated by Louis H. Roddis, Jr., vice-chairman of the board of Consolidated Edison, "Energy conservation is the one area where we can go to work right away and show immediate results. Conservation is also a long-range, as well as a short-term project." According to C. Howard Hardesty, if the U.S. saved 10% on total energy consumption, it would be the same as developing 200,000 new oil wells, or developing 2930 new coal mines, or building 211 additional nuclear plants.

Recently, the Council on Environmental Quality (CEO) proposed to the Federal Energy Office (FEO) a plan known as the "half-and-half" plan. This plan is based half on energy growth and half on energy conservation."Each BTU saved is a BTU that can be put to work elsewhere". Since 1947, U.S. energy consumption has more than doubled - from 33 to 75 quadrillion BTU annually. The department of Interior has projected U.S. energy consumption in the year 2000 at 192 quadrillion BTU and we would have to import 61 quadrillion BTU of oil and gas . This amount of imported energy source alone is already greater than our entire 1968 energy consumption. If the half-and-half plan is adopted, the U.S. energy consumption in the year 2000 will be at 121 quadrillion BTU, 71 quadrillion BTU less than the Interior's projection.

A voluntary conservation program has been advocated by many circles. But, as far as I can foresee, a voluntary program doesn't have much chance of succeeding. The main reason is that few individuals are actually aware of the technicalities of the energy problems to limit themselves. Likewise, expecting groups of people to limit energy consumption voluntarily in a concerted way probably would be frustrated by the necessity to predefine group priorities. Thus the only reasonable alternative is an enforced conservation program.

One conservation program which needs our national immediate attention is the hydrocarbon conservation program which has been recommended by the National Academy of Science - National Research Council (NAS-NRC) since 1968. The fossil fuels (petroleum, natural gas, coal) are needed for petrochemicals, synthetic polymers, etc... for which no suitable substitutes are at present available. They might also play a part in synthetic or bacterial food production. Thus they should not be spent in the generation of electricity, for heating, and for industrial purposes where substitutes can qualify. We must therefore initiate immediately a practicable and effective hydrocarbon conservation program.

These are a few problems of the new energy era. The whole nation must face them together, with all its technical forces and manpower.

PART I

ENERGY RESOURCES

I- PLENARY SESSION

CO-CHAIRMEN:
WILLIAM H. WEBB
JOSEPH T. ZUNG

CONFERENCE KEYNOTE ADDRESS

John B. Rigg
Deputy Assistant Secretary - Minerals
Department of the Interior

Before too many years have passed, I think, the people of the United States will be thankful that we had an energy crisis last year. For some Americans, it has meant real hardship. For many of us in government it has meant long, hard hours of work with seemingly little progress. But for most Americans it has meant little more than inconvenience. . .with homes and offices slightly colder than we might like, and those hassles with lines at the local filling station. So far, we've gotten off easily. We've had a warning, one strident enough to wake us up. And, apparently, we have taken heed. If we do now what has to be done to assure adequate energy supplies, then one day a few years from now we will be able to look back gratefully to the time and the circumstances that startled us into action.

Our new awareness is symbolized in several ways by this Conference. It has broad-based sponsorship. It encompasses almost every traditional and potential energy source, from fossil and nuclear fuels to the sun, the wind, the fuel cell, and our proliferating solid wastes. Industry's increasing concern with energy management also is properly emphasized. An average cutback of just 10 percent in industrial energy use, much of which could be achieved through relatively simple improvements in operations, could realize energy savings equivalent to 1.5 million barrels of oil per day. And by slowing down to conserve gas we are beginning to find out that we can not only save some money--and probably some lives--but also get to know our fellow citizens, and our country, a little better.

Of course, no amount of conservation can be expected to do the whole job. Our country and its population are still growing and our energy requirements inevitably will continue to rise. We still depend heavily on crude oil--much of it imported--and though we hope to lessen that dependency, it will take time. Meanwhile, we are still faced with the problem that confronted us even before the recent embargo: a shortage of the refinery capacity needed to transform crude oil into the various consumer products we require. As of last September, plans announced for new and expanded refining facilities would give us an additional 2 million barrels of daily capacity. We will probably need at least another 5 million over the next decade if we want to meet our growing requirements for petroleum products. And that assumes that we will be steadily reducing per capita demand all the time.

Even if enough refineries are built and we have access to adequate volumes of crude oil, we can be sure that the crude is going to cost us more, much more, than it has in the past. Already we are paying better than twice the price we paid for imported crude just a few months ago. Prices for domestically produced crude inevitably will rise as well, and the same can be said for natural gas as it becomes scarcer.

Among the fossil fuels, that leaves us with coal. And, as far as the Department of the Interior is concerned, coal is this country's best bet between now and the end of this century.

Why? Because coal is by far our most abundant energy source. We have almost 200 billion tons of it that we can recover economically right now with today's technology, and that is enough to last us for hundreds of years at the rate we are using it. The fact is, of course, that we are using it too seldom. Although coal represents nearly 90 percent of our total fossil fuel reserve, it now supplies less than 18 percent of our energy needs. In the face of what has been happening on the oil and gas scene lately, you'll have to admit that doesn't make a whole lot of sense.

The Secretary of Interior, Rogers Morton, doesn't think so either. In line with the President's Project Independence goal, Secretary Morton has committed his Department's resources to an all-out effort that will make coal the fuel for most of our country's stationary heat and power generation. To that end, an Interdepartmental Coal Task Force has been established to come up with policy recommendations. . .a "national coal strategy". . .that will point the way toward making coal once again our principal energy source. Thomas V. Falkie, our new Director of the Bureau of Mines was the Secretary's choice to head the Task Force, and he expects to have his group's recommendations in the Secretary's hands early this summer.

Meanwhile, Interior has budgeted substantially for energy research in the coming fiscal year--well over half a billion dollars. And the lion's share of that. . .nearly $400 million. . .is for research that in one way or another has to do with coal. We'll be working on many different facets of coal: exploration, extraction, refining and conversion, and the problems that can be anticipated in converting central power stations from oil to coal. And that is only the beginning of a greatly expanded effort because, as we all know, coal has plenty of problems. We are looking for markedly increased production--up to 2 billion tons annually by 1985--and the markets for that much coal depend to a large extent on our solving some of its problems.

Take environmental acceptability, for example, which has up to now presented a substantial barrier to wider use of coal under power plant boilers. Interior has asked for $343 million this fiscal year for R&D. Our R&D will include work on ways to overcome the sulfur problem, either by converting coal to low-sulfur fuels or by removing sulfur compounds during or followin g combustion. Over the next five years, we expect to be putting something in the neighborhood of $3 billion into the total R&D effort.

Sulfur is only one of coal's problems. Getting it out of the ground at the rate of 2 billion tons a year, and doing it in ways that minimize the risk both to the coal miner and the environment, is another. We may need a threefold increase in production in just a little over a decade. Just that increase alone is the equivalent of 280 new mines, each averaging 5 million tons a year. . .in terms of the capital investment required, somewhere between $20 billion and $30 billion. It would mean opening a new mine every week, if we had started three weeks ago.

And it will require new workers, perhaps up to 300,000 of them over the next ten years, who will have to be attracted and trained to work effectively and safely within a technological context that will be steadily changing. This will be steadily improving too. Health and safety in coal mining has improved in recent years, but that improvement has been accomplished primarily by the placing of greater emphasis on healthful and safe operations rather than by the introduction of advanced technology. Coal mining is still riskier than it has to be and we believe that the major improvements from this point on must come through the development of a safer and more healthful mining technology.

Interior is working, under the research provisions of the 1969 Coal Mine Health and Safety Act, to assure that. Our multimillion dollar mining research program attacks virtually every hazard encountered in coal mining today. We are working, for example, to make haulage and roof-support systems continuous in ways that will eliminate production bottlenecks as well as safety hazards. We're making good progress with a system for degassing coal seams ahead of mining, which promises not only to minimize the hazard of explosive methane, but also to make sizable quantities of gas available for residential use. And we expect to develop and demonstrate technology that can make longwall mining more widely applicable in this country, because we're convinced that it can yield real dividends on both the safety and productivity fronts.

Results from this sustained R&D effort are now beginning to come out of the pipeline, and I predict that the coal mining industry and the public are going to be impressed with them. Up at Prestonsburg, Kentucky, a new mine is being developed right now that will soon be a showplace for some of these results. There, equipment and techniques expressly developed for safer conventional mining will be demonstrated in actual mining practice. Moreover, although we purposely will not be striving for productivity in this operation, we expect that it will reveal opportunities for productivity gains. A similar demonstration, in a continuous mining section, is scheduled to begin later this year at a coal mine in Illinois.

Now the gains in health and safety that have been made so far, and those to come, must not in any way be compromised. At the same time, if coal is to remain competitive for the foreseeable future, productivity rates must be improved at underground and surface mines. Both have experienced productivity declines in recent years. We've asked for nearly $47 million to address the problem this year. The program will seek not only improvements in present mining methods but also wholly new technology and new mining systems. Secretary Morton has set the goal. . .a doubling of current productivity rates by 1985, and our R&D people are determined to reach it. They are also determined to solve the recovery challenge for the fuel values inherent in the thick coal seams of the West. Excellent progress is being made in Bureau of Mines experiments in underground coal gasification, and in systems for rapid restoration of surface mined land, which are essential for the extraction of coal in arid parts of the West.

We believe the practical, workable technology that will come out of this wide-ranging research and development effort is part of what the coal industry must have if it is to help meet the Nation's growing energy needs. But there is something else it must also have. And that something is a degree of certainty.

Before the industry can attract the capital and marshal the resources required for long-range investment in new mines, it must have some reasonable assurance concerning the framework within which it will have to operate, the conditions it will have to meet. What will be permitted in the way of surface mining, and what will be required in the way of reclamation? What will be the impact of air quality control regulations?

In this latter connection, it is interesting to note the findings of a recent study by the Interior Department's Bureau of Mines which compared the sulfur content of coals available to each Air Quality Control Region with the emission standards established for each region. . .standards now scheduled to go into effect on July 1, 1975. The Bureau found that roughly a third of the coal tonnage produced annually--somewhere between 200 million and 300 million tons--will not be burnable once the new standards take effect.

Such a prospect cannot help but dampen enthusiasm for any large scale heavy investment in new coal production capacity. Who is going to pour capital into a new mine, knowing in advance that he won't be able to market its product?

Strict enforcement of clean air standards would shut down half our coal-fired electric generating capacity and much of our industry. So, we can anticipate that some kind of relief will be forthcoming. But, the point is that the coal industry does not know what kind, or for how long, or under what conditions. And so would-be coal producers--operators of those 280 new mines that we need to more than double production by 1985--are waiting. The longer they wait, the longer the country will wait for coal, and the less likely the national prospect for energy independence.

The Interagency Coal Task Force that I mentioned earlier is facing up to this problem, and from that group will come answers that can break the paralysis of decision now gripping the coal industry.

From the way I've been emphasizing coal you may be guessing that I have a fat portfolio of coal stocks. Well, I don't. In fact, my industrial background had a lot more uranium in it than coal. Furthermore, I'm convinced that nuclear energy will play a mighty big role in the energy future of this country, as will our vast western deposits of oil shale, our tar sands, our geothermal deposits, and power from the sun and the wind. Our country is just beginning to grow and it has abundant energy resources to nurture that growth. All of them can and will be used in time.

But, superabundance and a unique combination of circumstances have made this the time for coal. By meeting today's challenge, coal can give us the time we need to develop and use all of our energy resources in the best interests of all of our people.

II - NUCLEAR ENERGY

CHAIRMAN:
ALBERT E. BOLON

PROSPECTS FOR NUCLEAR FUSION POWER

William C. Gough
U.S. Atomic Energy Commission
Washington, D.C. 20545

ABSTRACTS

The prospects for fusion power are discussed including the need for fusion, its environmental advantages, and the research results that form the basis for present confidence that the program will succeed. The steps remaining before commercial fusion power will be available are outlined. Exploratory ideas for second generation fusion electric power plants, and non-electrical applications of fusion technology and reactors are briefly covered.

* * * *

The closest thing to a single solution for the world's many problems would be an unlimited supply of cheap, clean energy. The world could then feed and house its growing population, alleviate the mineral shortages that produce international tensions, clean up the long suffering environment, and enjoy a stupendous number of other benefits. [1]

The exciting thing is that cheap, clean energy is not an idle dream. Scientists right now are converging on the remaining technological obstacles that still keep us from this powerful solution to so many problems.

The source of this fantastic power is the process known as thermonuclear fusion. All of the stars, including our sun, create their vast energies by the fusion process. On earth, hydrogen bombs, which depend on fusion reactions, have convincingly demonstrated the potency of this source of energy, but many people do not realize that the same power that can be used for such horrifying destruction can equally well be used for human betterment.

Fusion does not depend on fossil fuels, which are limited and dwindling, but on fuels that are extremely abundant. Certain types (or isotopes) of hydrogen can be joined, or fused together, with a tremendous release of energy. For instance, the world as a whole has 8,300 Q of known and probable reserves of lithium, one likely fusion fuel when converted to the hydrogen isotope tritium. [2] Seawater contains another 21 million Q of lithium. Q is a unit of heat measurement equal to a billion billion BTU, or British Thermal Units. The entire world now consumes about a fifth of a Q each year. The situation is even more favorable when we consider deuterium, a hydrogen isotope that is also a fusion fuel. The oceans contain 7.5 billion Q of deuterium, enough to run the earth for billions of years. The procurement of deuterium from the oceans, where it occurs as one part in every 6500 parts of hydrogen, is comparatively easy and the water can be returned virtually unchanged to the oceans. Figure 1 summarizes this data.

ENERGY USE

	Q (10^{18} BTU)
U.S. ELECTRIC GENERATION	0.015
U.S. ENERGY CONSUMPTION	0.06
WORLD ENERGY CONSUMPTION	0.17
10^{10} PEOPLE AT U.S. PER CAPITA CONSUMPTION	2.9

FUSION ENERGY RESERVES

KNOWN AND INFERRED U.S. LITHIUM RESERVES	500
PROBABLE WORLD LITHIUM RESERVES	8,300
LITHIUM CONTENT OF SEA WATER	21,000,000
DEUTERIUM CONTENT OF SEA WATER	7,500,000,000

Figure 1

Fuel costs for fusion are almost completely negligible. Essentially every nation of the world possesses these fuels. Thus fusion would eliminate for all future generations what has been a major cause of international tension and wars; the conflicts over the energy resources that are essential for the survival of industrial societies. [3]

The fusion process is relatively clean in sharp contrast to the polluting combustion of fossil fuels. Fusion does not release carbon dioxide or other combustion products into the atmosphere and it does not burn the earth's oxygen or hydrocarbon resources, which could be used as raw materials for many chemicals if they were not burned for heat. The extraction of fusion fuels from the land or seas would present a negligible impact upon the environment.

Another important advantage of fusion is that no radioactive wastes are produced from the burning of the fuel, although radioactivity is produced in the structure of the plant due to the neutrons generated in most fusion fuel cycles. For a given fuel mixture, the extent of this induced radioactivity depends upon the structural materials used. This selection is up to the reactor designer, and studies have shown that the amount of this radioactivity can be kept relatively low. In addition, the plant must be carefully designed to prevent leakage of tritium fuel from the reactor. Tritium, however, is one of the least toxic radioactive materials. Some common fusion fuel cycles are given in Figure 3 as well as the reactions required to produce or "breed" tritium.

FUSION FUEL CYCLE

Reaction	Ignition Temperature
$D + T \rightarrow He^4 + n + 17.6$ Mev	50,000,000°C
$D + D \rightarrow He^3 + n + 3.2$ Mev; $D + D \rightarrow T + H + 4.0$ Mev	300,000,000°C
$D + He^3 \rightarrow He^4 + H + 18.3$ Mev	500,000,000°C
$H + Li^6 \rightarrow He^3 + He^4 + 4.0$ Mev	900,000,000°C

TRITIUM BREEDING

$n + Li^6 \rightarrow T + He^4 + 4.8$ Mev

$n + Li^7 \rightarrow T + He^4 + n - 2.5$ Mev

Figure 2

The fusion process is also remarkably safe. A fusion reactor is inherently incapable of a "runaway" accident. In fact, the fusioning hydrogen gas or "plasma" is so tenuous that there is never enough fuel present at any one time for a dangerous nuclear excursion to occur.

Since no solid material can exist at the temperature range required for a useful energy output from fusion (about 100 million degrees C) the principal emphasis has been on the use of magnetic fields to hold the hot gas or plasmas from the walls. These invisible magnetic fields are hundreds of times stronger than what people usually experience using a household magnet. Other methods such as the use of electrostatic fields or inertial confinement (as when a solid pellet is ignited to fusion temperatures by a high power laser) are also being researched. [4]

The first fusion reactors will very likely operate using the deuterium-tritium (D-T) fuel cycle since the plasma physics conditions are easier to achieve than in any other fusion fuel mixture. Figure 3 and 4 are conceptual designs of DT fusion reactors.

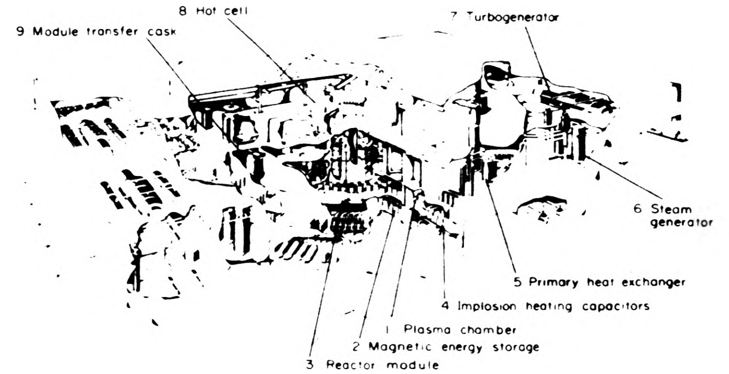

Figure 3—Conceptual design of a theta pinch fusion power plant done jointly by the Los Alamos Scientific Laboratory and the Argonne National Laboratory.

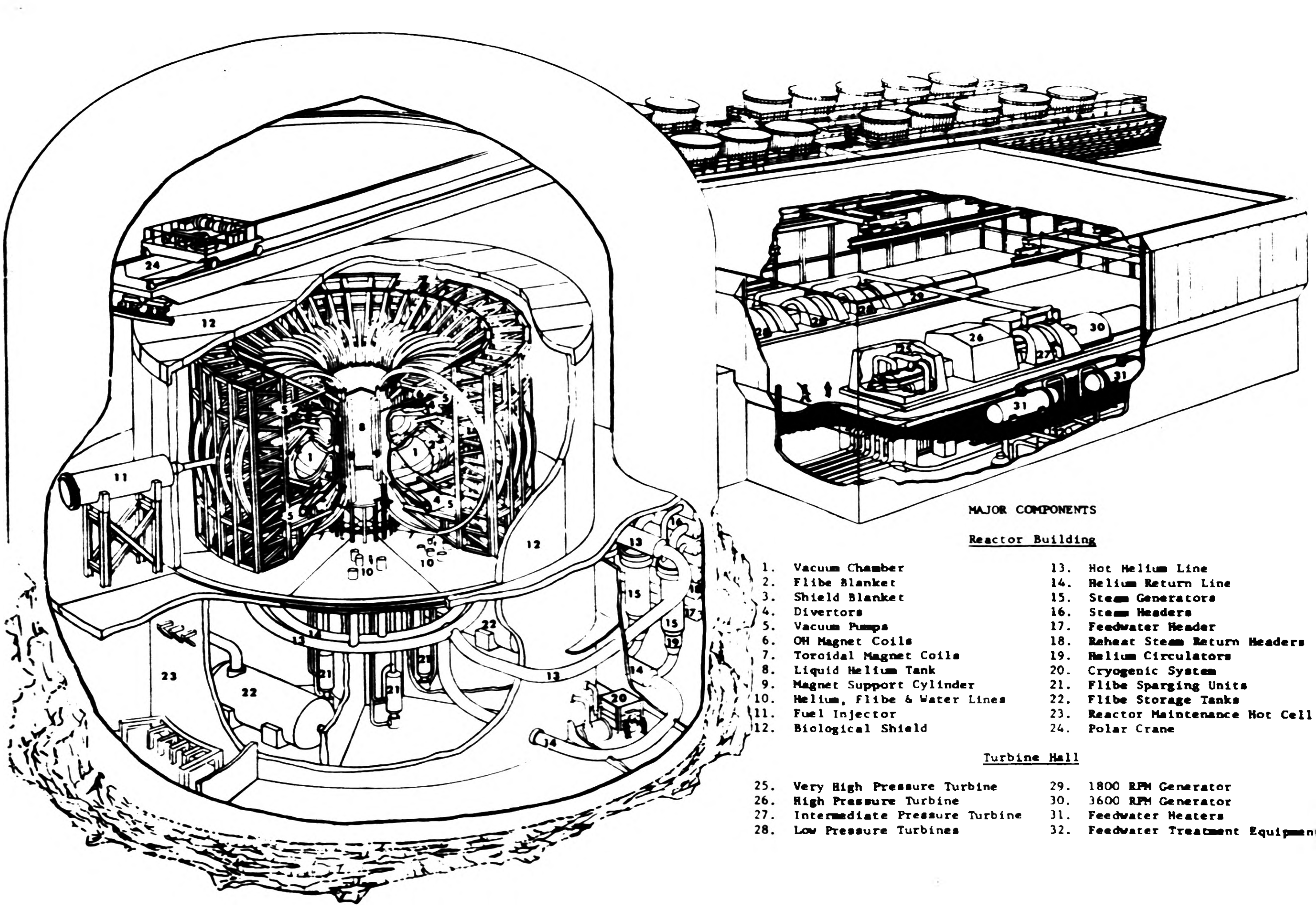

Figure 4—Conceptual design of a tokamak fusion power plant done by the Princeton University Plasma Physics Laboratory. 2,100 megawatts of electricity is produced at 40% efficiency.

The waste heat from such plants will about equal that produced in the most efficient fossil fuel or fast breeder power plants of similar size planned for the future. Figure 5 illustrates thermal energy conversion from a fusion reactor.

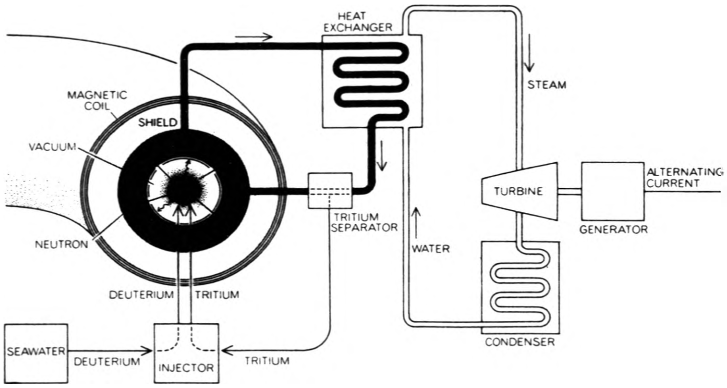

Figure 5—THERMAL ENERGY CONVERSION would be most effective in a fusion reactor based on a deuterium-tritium fuel cycle, since such a fuel would release approximately 80 percent of its energy in the form of highly energetic neutrons. The reactor could produce electricity absorbing the neutron energy in a liquid-lithium shield, circulating the liquid lithium to a heat exchanger and there heating water to produce steam and thus drive a conventional steam-generator plant. The reactor core could be either linear or toroidal. Alternately, helium could be used as coolant with the lithium in a solid compound. (From "Prospects of Fusion Power" by Gough and Eastlund. Copyright 1971 by Scientific Americas, Inc. All rights reserved.)

The environmental advantages and safety of fusion reactors may permit the siting of fusion power in urban areas where a good use could be found for the waste energy, such as the heating of buildings or the processing of sewage. As one moves towards the more advanced fusion fuel cycles the need for making tritium fuel from lithium in the reactor disappears and the number of neutrons produced progressively becomes less and less until it is insignificant.

As the fusion energy increasingly becomes available as charged particles rather than neutrons, the production of electricity directly from the ultra-high temperature fusion plasma at extremely high efficiencies becomes possible. Advanced fuel cycles and direct energy conversion are considered possibilities for second generation fusion reactors. At present, very limited work is underway on such possibilities due to the expensive and high risk nature of such research and development. Figure 6 illustrates direct energy conversion from a fusion reactor.

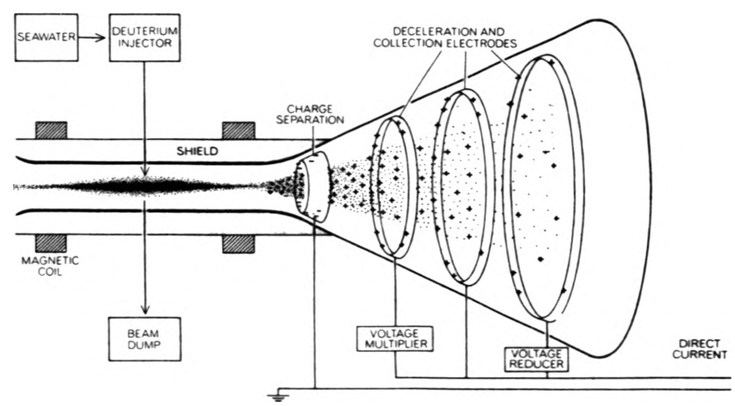

Figure 6—Direct energy conversion would be more suitable for fusion fuel cycles that release most of their energy in the form of charged particles. The energetic charged particles (primarily electrons, protons, and alpha particles) produced in the core of a linear fusion reactor would be released through diverging magnetic fields at the ends of the magnetic bottle, lowering the density of the plasma by a factor of as much as a million. A large electrically grounded collector plate would then be used to remove only the electrons. The positive reaction products (at energies in the vicinity of 400 kilovolts) would finally be collected on a series of high-voltage electrodes, resulting in a direct transfer of the kenetic energy of the particles to an external circuit. (From "Prospects of Fusion Power" by Gough and Eastlund, Copyright 1971 by Scientific American, Inc. All rights reserved.)

Over the last few years, the fusion program has entered a period of transition as we prepare to undertake the massive effort required to turn a laboratory research program into a major new energy source. Pictures of some fusion laboratory experiments are shown in Figures 7, 8, and 9.

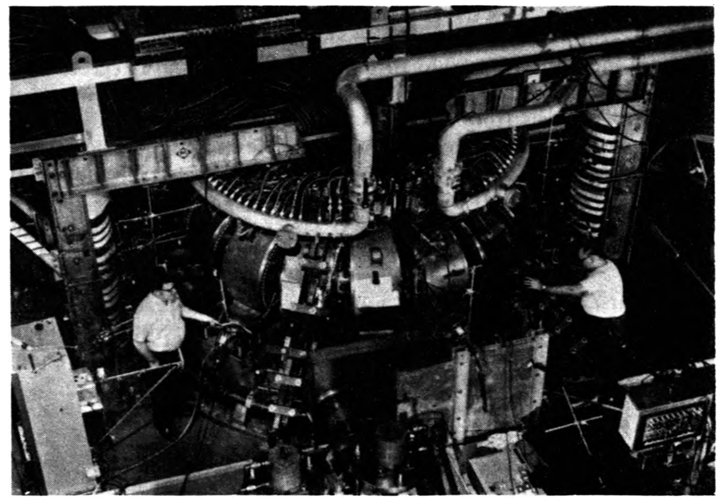

Figure 7—The Symmetric Tokamak (ST) at the Princeton University Plasma Physics Laboratory in New Jersey was the first tokamak in the United States.

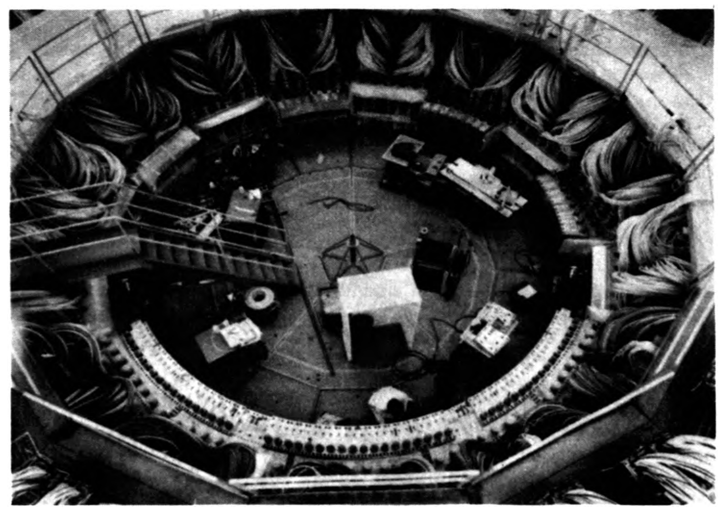

Figure 8—The Scyllac torus experiment at the Los Alamos Scientific Laboratory in New Mexico is a theta pinch device 25 meters in diameter.

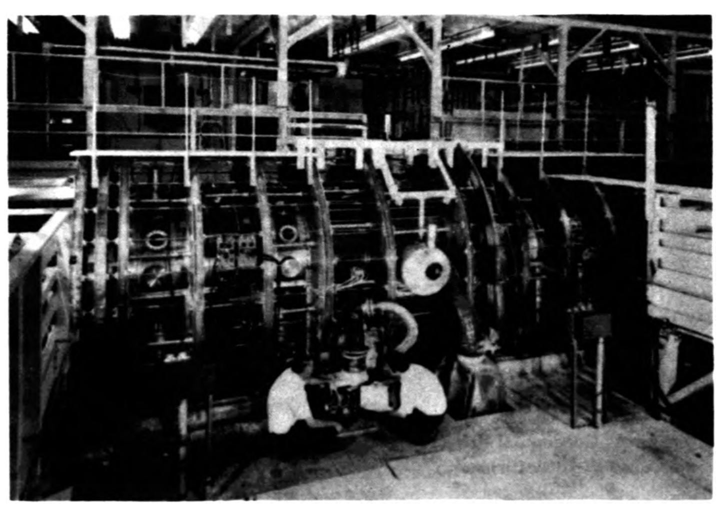

Figure 9—The 2X-II mirror experiment at the Lawrence Livermore Laboratory in California has produced plasma over 50,000,000 °.

In a day when people spend hours of their time waiting for energy at the local gas station, a natural question is when will the abundant cheap energy from fusion be available? Unfortunately, fusion will not be here in time to relieve the present energy crisis which results from having energy in the wrong form for existing technologies. You just can't burn rocks in your gas tanks even though we still have plenty of energy in the form of coal and uranium in the United States. The clearest warning for the present crisis came in 1970 when the rate at which we were finding domestic oil reserves failed, for the first time, to exceed the rate at which we were consuming oil. The current energy situation results from the inaction on the part of this nation to take anticipatory steps–for example research and development work on coal gasification and liquification.

The present energy problems are a precursor to move serious but equally predictable future crises. Ones that will involve the closely interrelated questions of energy supplies, material availability, and environmental degradation. Plentiful fusion energy would be a major factor in averting a future crisis so that you and your children could experience a good standard of living in a healthful environment. The development of a major new technology like fusion energy is expensive and the lead time is long, yet it may be needed sooner than many people are willing to admit.

To appreciate the steps remaining before commercial fusion power will be available to you let us look back and see how far we have already progressed. The inception of the fusion power program was in 1952 over twenty years ago. The accomplishments to date have been significant. The technologies for creating and studying million degree plasmas were developed, a new field of physics for understanding fusion plasma has evolved, experts in this new field of physics are now graduating from American universities, the barriers that appeared to exist for achieving the temperature, densitites, confinement conditions necessary for a fusion reactor have all been broken in individual experiments, and recently fusion experiments with designs heavily dependent upon the new theories have operated as predicted. In fact, small amounts of fusion energy have been produced under controlled conditions in our laboratories–but far less than the amounts necessary to achieve net power. We now believe that there is no basic law of physics that keeps us from economic fusion power. Although many years of hard work have gone into these accomplishments, the cost to the American taxpayer has been less than the cost of a single moon shot.

Our next goal on the road to fusion power is to achieve all three of the essential fusion conditions–temperature, density, and confinement time–in a single experiment that produces net energy. There are many possible pitfalls ahead since physics and engineering uncertainties remain to be better understood. Yet we are confident that with adequate funding, solutions will be found to any problems that arise. We project that the much larger "energy breakeven" experiment will operate in the 1980-82 timeperiod. Recent analyses have indicated that by tailoring the plasma in the experiments in certain ways, "breakeven" conditions might be achieved in the late 1970's using the smaller experiments now under construction. An intensive effort to evaluate this possibility is now underway. [5] Figure 10 shows the "breakeven" plasma conditions for both the tailored "two component" case and the familiar Lawson criteria.

In addition to the plasma physics challenges that may lie ahead as we move towards fusion power conditions, extensive engineering developments must be carried out–for example in materials, superconducting magnets, plasma heating technology, neutronics, and tritium chemistry. [6] Such work will enable experimental fusion power reactors (20-100 million watts electrical) to be operated in the mid and late 1980's and a demonstrated fusion power reactor to be operated about the year 2000.

The engineering and materials development for these long lead time systems will cost billions. The Presidents' fiscal year 1975 budget request to Congress included a five year plan for the fusion program totaling $1.2 billion. A number of this magnitude needs to be put into perspective. For example, this amount is $200 million less than the cost of the new 2300 mega-watt electric power plant planned by Consumers Power Company for Quanicassee, Michigan. Even assuming a greatly reduced growth rate in the use of energy in the United States, more than 500 such nuclear fission power plants each as large and each at least as expensive will be needed by the year 2000. This is in addition to the large number of fossil fuel plants scheduled. The present budget of the AEC's Division of Controlled Thermonuclear Research is $56.8 million and it is anticipated that this budget will increase considerably next year.

The specialized manpower required for the initial stages of a rapidly expanding fusion program exist. There are now an estimated 1500 plasma physicists in the United States; the fusion power program employs only about 300. Engineers, chemists and physicists trained in the space, weapons and nuclear fission reactor programs have the necessary backgrounds to perform the projected tasks in fusion materials research, tritium studies, component development, and system engineering.

'BREAK-EVEN' PLASMA CONDITIONS FOR FUSION POWER

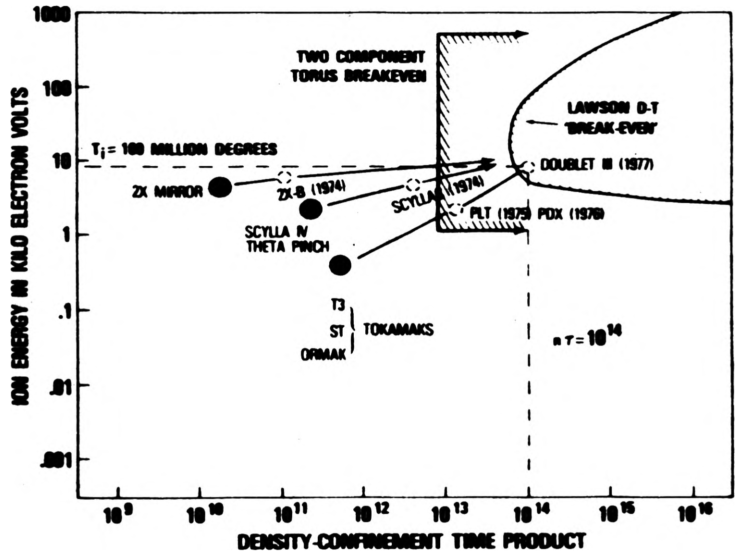

Figure 10

Fusion technology can do more than lead to a system for producing electricity. Fusion will also provide a unique means of producing large quantities of electromagnetic radiation, energetic charged particles, and high energy neutrons, which will yield important benefits to mankind. [7]

A strategy for a liveable long-term future might include:

1. A stabilized world population.
2. A closed materials economy where wastes are converted into new raw materials.
3. New industrial and agricultural processes, (including recycling) that avoid the undesirable byproducts resulting from today's widespread use of energy in the form of chemical compounds.
4. An abundant energy source that is highly compatible with the earth's environment.

Besides meeting need number 4 (abundant energy), fusion technology may help us to meet needs two and three by creating high temperature plasmas that are ideal for converting energy to forms that can be tailored to do specific jobs.

THE POTENTIAL OF FUSION

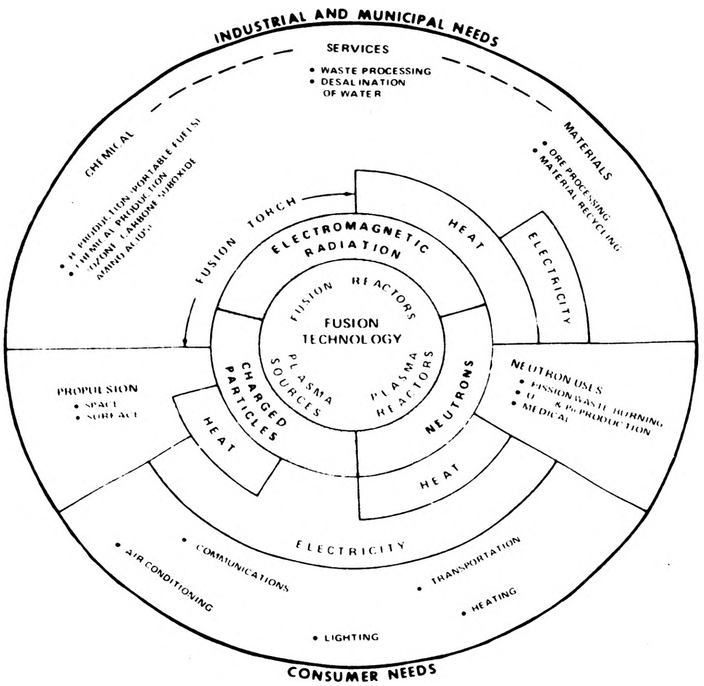

Figure 11—This chart suggests the many ways in which fusion technology will meet human needs. In the center of the wheel, three stages in the development of fusion technology are indicated:

I. *Plasma sources,* where little or no fusion energy is generated. This stage is approximately where scientists are now.

2. *Plasma reactors,* which operate at ultrahigh temperatures and produce fusion energy but no net power; that is, more energy has to be put into the system than can be taken out. This stage will be reached with the coming large-scale fusion experiments.

3. *Fusion reactors* producing net power. This is the goal of the current fusion power program. At this stage, a relatively small amount of power put into the system will generate a large amount of fusion power.

All three stages make available three primary forms of energy:

I. High-intensity radiation, ranging from X-rays through ultraviolet to infrared.
2. Ion and electron kinetic energy associated with the plasma.
3. High energy neutrons.

All three of these primary forms of energy can be converted to heat or electricity for many applications, or they can be used directly, as in the case of neutrons which burn up fission waste.

Recognizing the unique potential of fusion plasmas, my colleague, Dr. Bernard J. Eastlund, and I put forth the concept of the "fusion torch". [8] The general idea is to use the ultrahigh-temperature plasmas, quite possibly directly from the exhaust of a fusion reactor, to vaporize, dissociate and ionize any solid or liquid material. [9]

The fusion torch might eventually make possible the steady-state economy, in which all wastes become raw materials for new products. More immediately, such techniques offer the possibility of processing low-grade mineral ores or producing portable liquid fuels by means of the plasma system.

The fusion torch could be used to transform the kinetic energy of a plasma into ultraviolet radiation or X-rays by the injection of trace amounts of heavy atoms into the plasma. The large quantities of electromagnetic energy generated in this way could be used for many purposes desalting seawater, heat, and producing hydrogen. Such new industrial processes should be less likely to pollute the environment than traditional methods. Industrial processes based upon fusion technology are just starting to emerge and could come into widespread use during the next ten years.

Fusion reactors operating on deuterium-tritium fuel would produce large quantities of neutrons. Although one usually thinks of moving directly from nuclear fission reactors to pure fusion reactors, we could possibly move through a stage where fusion-fission are combined in a single system to form a hybrid reactor. [10] Such systems involve the coupling of neutrons from fusion reactors with nuclei of uranium or thorium to produce a multiplication of energy and thus less stringent conditions for net power. In addition to generating electricity, the hybrid could provide fissionable material for existing nuclear fission power reactors during the years when pure fission power is phasing into our total energy producing system. Another use for the neutrons from fusion would be to reduce the problem of fission wastes. From recent studies it appears that fusion reactors can potentially transmute most of the high level wastes from a fission economy into stable or short half-lived ash. However, the problem is extremely difficult and it will require considerable effort to assess fully the practicality of these ideas." [11]

The fusion program in the United States involves government laboratories, private industry, and universities. In addition to the federal government, the public utilities are now funding a small but growing program in fusion research. The U.S. fusion program represents about one fifth of a close cooperative worldwide endeavor to meet a major problem of mankind. The world fusion effort can be divided into four parts—the largest is in the Soviet Union, followed by Euratom nations, then the United States and finally the rest of the world (principally Japan, Sweden, Australia and Canada). The cooperative nature of this program has been spearheaded by world conferences sponsored by the U.N.'s International Atomic Energy Agency. An expanded exchange of U.S. and Soviet scientists to work in each others' laboratories is now being undertaken to augment the already extensive mutual exchanges that exist between the U.S. and western nations. One can envision the time when space communications technologies are used to accelerate the world fusion power effort. This could be accomplished by connecting via satellite the twenty major world fusion centers so that remote terminals in all laboratories would have access to central fast computers and TV communications would link the top world fusion scientists so they could interact directly, continually and quickly. In the United States next year we have planned a large computer facility with interconnecting links to all major U.S. fusion laboratories.

There is no substitute for energy—you must have it to be a strong person, a strong nation, or a strong and healthy world. Indeed energy is a weapon, as increasing numbers of persons are beginning to realize—and fusion energy is truly a weapon for world peace and betterment.

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ALTERNATE ENERGY REMOVAL MODES FOR NUCLEAR POWER REACTORS

Robert L. Carter

College of Engineering
University of Missouri - Columbia

ABSTRACT

Attention is focussed upon the unique qualities of high energy fission particles, and upon the fundamental limits to the direct removal of their kinetic energy by electrostatic means and by cyclotron resonance deceleration. Efficiencies of secondary and tertiary product ionization and excitation produced by fission particles are examined. The potential for delivery of power through various non-thermal modes is discussed, and the significant unknowns relating thereto are identified.

INTRODUCTION

Direct Energy Conversion Research in the 1950's

The early era of fission reactor development saw a wide range of concepts examined through the research and development stage. Homogeneous and heterogeneous designs employed fuels which were solid, liquid, gaseous, slurry, metallic oxide or carbide. Water, heavy water, graphite, organics, Be, BeO, ZrH_2, or plastics were used as moderators, and virtually every conceivable fluid of low cross-section was considered for use as reactor coolant.

A plethora of novel energy conversion schemes were also explored.[1,2,3] Reactors were built employing semiconducting thermoelectric convertors, and detailed designs were developed for reactors containing cascades of thermionic cells centered on uranium fuel elements to permit direct conversion topping cycles. Studies of fission-electric cell reactor designs were carried out wherein energetic fission particles would be made to do work directly on repulsive electric fields. Miley's comprehensive review[4] includes examination of the practical difficulties met with in this approach.

The Winner! - Prior Proven Technology

Early workers in the nuclear energy field were, for the most part, trained as scientists, not as engineers. In the 1950's, as the various reactor development programs began to move into the design and prototype construction stages, individuals trained as engineers were called upon to assume an increasing fraction of program responsibilities. It soon became evident to these people that the scientists' preference for a "sealing wax and string" laboratory feasibility approach was far removed from the engineering necessitated when long-term dependability became the controlling criterion. The submarine reactor program, in particular, found it necessary to move away from more novel designs toward a design with no uncertainties with respect to containment vessel integrity and materials compatibility. With a minimum number of novel ingredients, such a design was employed in the first nuclear power station, the Shippingport PWR (pressurized water reactor). A reactor utilizing basically similar technology, the Dresden BWR (boiling water reactor), became the second to provide steady feed to a commercial electric power grid.

After a few years operation of these reactors, it became clear to utility management that such light water cooled and moderated (LWR) reactors could be economically competitive with conventional fossil-fired steam power plants. The subsequent rapid acceptance and building of a large number of LWR's by utility companies soon made it apparent that the available U-235 resources would be committed before the end of the 20th century. The breeder then became vitally important as a research and development objective. Remaining thermal neutron research and development work was redirected toward fuel element life extension, matters relevant to reactor safety, fuel safeguards practice, spent fuel transportation and reprocessing, and toward the accomodation of long-term changes to be anticipated in LWR components. Little interest has been shown in further exploration of direct energy conversion for application to fission reactors.

Is There Undiscovered Gold to be Mined Here?

An important reason for the choice of the LMFBR (liquid metal cooled fast breeder reactor) over the GCBR (gas cooled breeder reactor) or the MSBR (molten salt breeder reactor) for the breeder development program was the availability of substantial data concerning the use of molten sodium as a low pressure, high temperature reactor coolant. This had been developed in the EBR (experimental breeder reactor) and in the now-defunct sodium-cooled graphite-moderated reactor (SGR) programs. The LMFBR offers the opportunity of gaining not only the low fuel cost of a breeder cycle, but also thermal efficiency comparable with that attainable in modern fossil-fired steam plants.

While the attainment of 40% thermal efficiency would provide an important gain over the 30%+ now obtained in LWR plants, the fact that nearly twice as much heat is thrown away at the power plant as is provided to the customers served by the electrical distribution network seems most regrettable. This becomes especially distressing in view of the Nation's growing energy shortfall. It should be pointed out that this limitation arises from the thermodynamic characteristics of the practical heat conversion cycle. It does not arise from a limitation in the attainable source temperature. The inherent energy of fragments emitted from the fission reaction corresponds to the equivalent energy per particle of a hypothetical working gas at a temperature of over a trillion degrees (10^{12} C); even fossil fuel flame temperatures are of the order of 1800° C.

GOING BACK TO THE SOURCE OF IT ALL

The Cascade of Energy Degeneration

Better than 94% of the fission energy is recoverable as heat transferred from the reactor core by the coolant. The remaining 6% escapes by way of the intransigent neutrinos and through the residual stored nuclear energy of radionuclides removed with the spent fuel. It should be noted that if direct conversion of fission particle energy only were employed, only about 83% of the energy will be tapped. Thus, even if 100% conversion efficiency were attained, less than 87% of the energy released in the reactor could be utilized in the cell, the balance would have to be removed as thermal energy from the reactor volume.

Fission fragments are projected isotropically into the fuel medium at sub-relativistic velocities with initial degrees of ionization ranging from 16 to 22.[4] The stopping power of the medium, dE/dr (Figure 1) decreases as the particle picks up electrons and loses its high degree of coulombic effectiveness for long-range interactions. Near the end of its range, the decrease in the stopping power reverses and it passes through a lower maximum value. This is a characteristic of fixed-charge particle behavior when the particle attains velocities approximately matching that of bound electrons within the medium. The transit lifetime of a fission particle within a condensed medium is about 10^{-12} second.

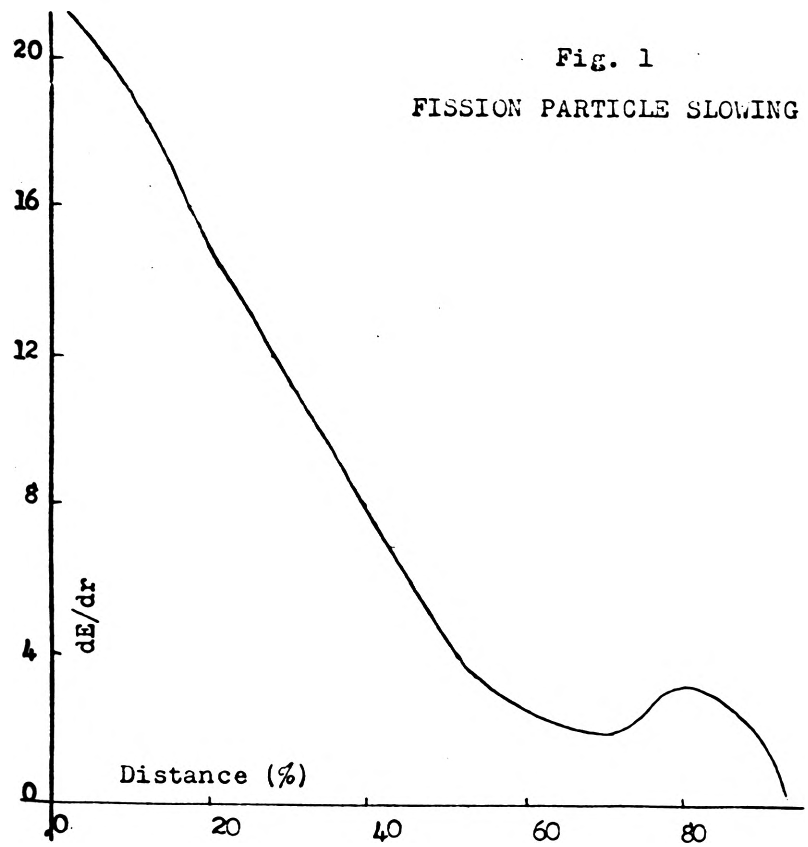

Fig. 1

FISSION PARTICLE SLOWING

The immediate depositories of fission particle energy in the medium traversed, in order of decreasing importance are

kinetic energy of heavy recoil atoms
excitation of recoil and non-recoil atoms
ionization of recoil and non-recoil atoms

If the fuel medium is UO_2, uranium atoms pick up about 60% of the recoil particle kinetic energy, and oxygen atoms about 40%. The recoil atoms have smaller charges than the incident fission particle, hence exhibit transit lifetimes of about the same duration as the primary fission particle (10^{-12} seconds). The internal excitation lifetimes for atom electronic states range from 10^{-14} seconds or longer for metastable states. Ionization states may show much longer lifetimes, persisting for up to 10^{-3} seconds in some cases.

The secondary recoil ion, in turn, traverses a branch path of its own, leading to deposition of its kinetic energy as

kinetic energy of tertiary recoil particles
excitation of electronic states
ionization

This and subsequent degradation of fission particle kinetic energy toward the ultimate conversion to electrical power through conventional thermodynamic working fluid driven turbogenerator means is shown graphically in Figure 2. Note that conventional energy conversion begins with coolant temperature elevation near the bottom of the cascade. The fission cell undertakes conversion of energy from the top of the cascade. It is the thesis of the present paper that the possible advantages to be gained by extraction of energy at intermediate levels of the cascade should be examined more thoroughly. In particular, two excitation levels having relatively long lifetimes; energetic free electrons and metastable excited electronic levels, should be given careful attention.

Dusty Corners

High temperature conversion devices without moving parts are the most conservative of the "wild schemes". The thermionic diode and the semiconductor thermocouple are two such. The inherent efficiency of both of these convertors is limited to less than 20% by the presence of by-pass modes of heat transport through conduction and thermal radiation. Design of such delicate electrical devices for long-term in-reactor operation appears formidable.

The same type of problem haunts the in-reactor fission electric cell. While the fission fragment slows in a medium while exhibiting an average electron charge of seven from an initial energy of about 90 million electron volts, it may entrain a cloud of possibly forty attendant electrons. As a consequence, special electrostatic or magnetic deflectors must be used to divert the electrons if the electrostatic energy of the fission fragment is to be collected. In his monograph[4], Miley recounts the many problems met with in this undertaking. Standing back of all again is the haunting spectre of the impossibility of maintaining high electrostatic potential gradients and stable electrical insulation in an intense radiation environment.

JUST SUPPOSE

Electron Cyclotron Resonance Maser

The author of this paper has proposed the induction of coherent cyclotron resonance emission from within a plasma whose high electron temperature is maintained by fission fragment ionization. To permit any appreciable energy yield, ω_{ce}/ν would have to be appreciably greater than unity (ω_{ce} being the electron cyclotron resonance frequency and ν the electron scattering frequency). A large superconducting coil surrounding the reactor would allow the achievement of a fairly uniform magnetic field of 4 teslas within the core, yielding ω_{ce} for electrons of

$$\omega_{ce} = \frac{eB}{m} = 7 \times 10^{11} \text{ sec}^{-1}$$

The peak kinetic energies of recoil electrons trapped within this field would be 400 eV, corresponding to velocities of 1.3×10^7 m/sec. For electron collison frequencies to be less than $7 \times 10^{11} \text{sec}^{-1}$, the electron mean free path will have to be greater than

$$\lambda_{coll} = v/\omega_{ce} = \frac{1.3 \times 10^7}{7 \times 10^{11}} = 1.9 \times 10^{-5} \text{ meters}$$

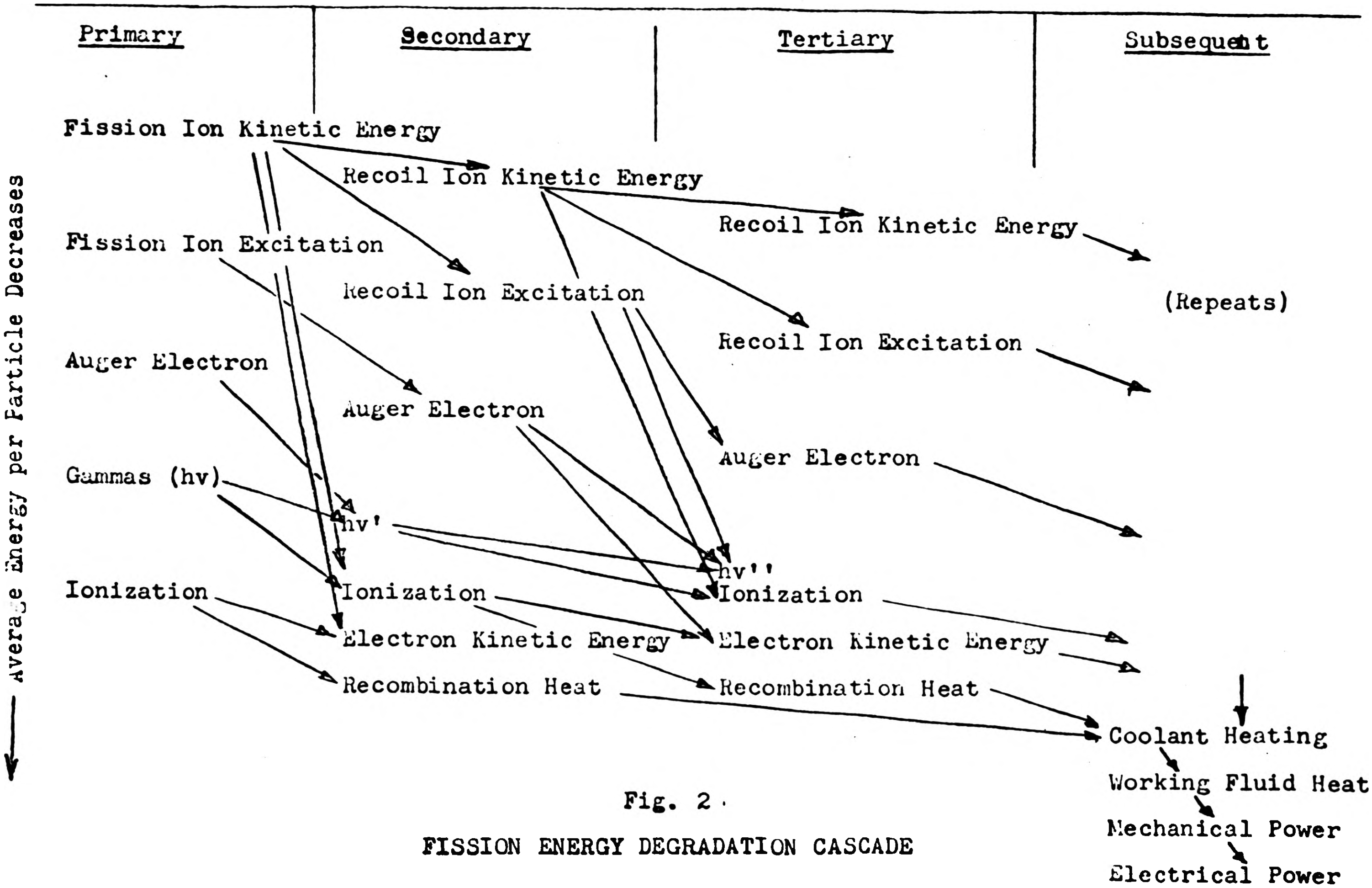

Fig. 2

FISSION ENERGY DEGRADATION CASCADE

This condition would be met in a 700°C (1300°F) alkali metal vapor at 1/10 atmosphere pressure,[6] and presumably would be approximately met by a fissile gas (say $U^{235}Cl_4$) under these conditions. To meet criteria for criticality such a reactor would have to be at least 10 meters in diameter and be surrounded by an efficient neutron reflector.

The wavelength of the cylotron resonance radiation existant as standing waves in the active gaseous medium will be of the order of 0.3 mm. To permit such a wave to build up to a self-sustaining level in the fissioning medium, it will be necessary to provide a high-Q multimode sub-millimeter microwave cavity within a reasonably uniform magnetic field. The homogenous reactor core will permit the advantages of continuous core fuel reprocessing (Figure 3). It remains to be seen just how multi-megawatts of submillimeter microwave power could be distributed and utilized.

X-Ray "Light Bulb Reactor"

The symbol "hν" in the cascade diagram (Figure 2) represents radiationless transfer of quanta from one ion to another in solids and liquids. It represents the exchange of visible, ultra violet, X-irradiation and γ-irradiation in gases. If the gas within which fission particles are being decelerated is highly ionized, say +6 on the average, the electromagnetic spectrum of excitation relaxation radiation will be shifted toward shorter wavelengths. This opens the possibility of removal of a significant fraction of energy from the active core as X-radiation.

Such a highly ionized gas could be contained through the use of magnetic fields, in a manner similar to that used to contain a fusion plasma of deuterons and tritons in the CNF (controlled thermonuclear fusion) program. Much of the work done in this program could be used in studying the feasibility of such an XLR concept.

Metastable Species

The clearing of political obstacles preventing the construction of a pipeline to the north slopes of Alaska was an important step in helping alleviate the immediate petroleum shortage in the contiguous forty-eight states. It also opened an important option for manufacture in northern Alaska of other commodities amenable to pipeline shipment. The possibility of achieving a nuclear power reactor design wherein an appreciable portion of the fission energy is converted to energy of metastable chemical species will be greatly

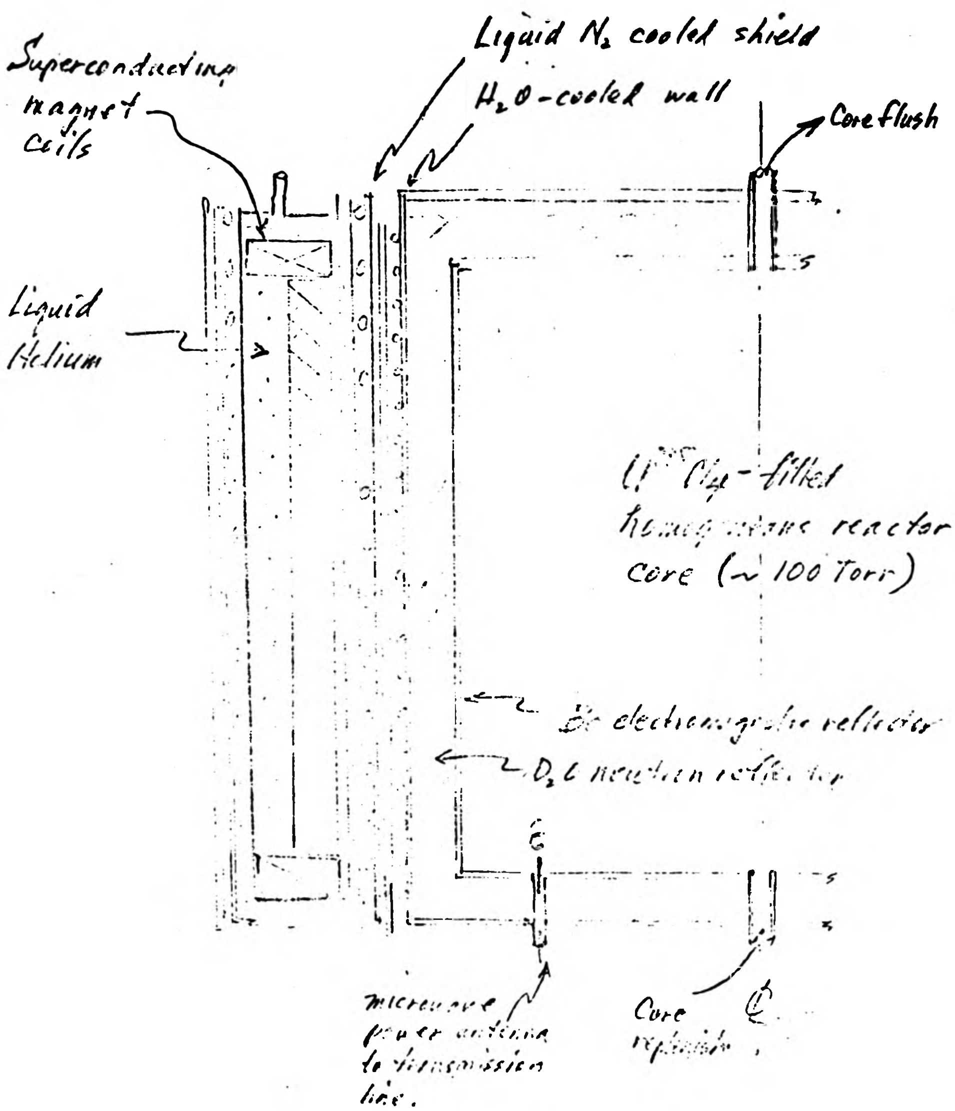

Fig. 3

ELECTRON CYCLOTRON RESONANCE
NUCLEAR GENERATOR

enhanced by operating the reactor at very low temperatures. The availability of the neighboring Arctic Ocean would make this feasible. Logistics of nuclear fuel supply to such a remote region would not be a problem, because of its small volume. If yet lower heat rejection temperatures are desirable, shepherding icebergs to the heat rejection interface with tugboats seems a viable possibility.

There is already at hand considerable experience with the forming of metastable species whose excess energy is derived from the fission process. While it is regarded as a nuisance, we must contend with the low temperature synthesis of undesired hydrogen in boiling water reactors. We also commercially produce polymers within intense gamma or beta fields. As in those cases, the exceedingly high excitation density achievable in the fission particle or recoil particle tracks will permit unique free radicals to be formed. Such "excitocules", when identified for various gases thus "intimately" irradiated, will open up a variety of possibilities for plasma chemistry systhesis and for pumping of chemical lasers.

<u>Where May Break-Throughs be Sought?</u>

If any of us had the answer to the question, we would be at home working instead of talking with one another here. Four basic research areas seem to hold promise for opening the doors to the intermediate energy conversion area of Figure 2. Despite limited immediate applications interest, intensive investigation of processes in fissile gaseous media should be undertaken. In addition to studies of neutron multiplication, scattering and absorption processes, the kinetics of the massive ion "tree" need be subjected to theoretical and experimental investigation. This should include ancillary description of ionization and excitation states produced and their decay processes through emmission of Auger electrons and photons. The behavior of the free electron gas should be determined experimentally using established plasma diagnostic techniques.

Thirdly, the behavior of an optically active medium which exhibits regenerative cyclotron resonance in a magnetic field should be explored. Such work may be performed initially using media excited by non-radioactive ions or by electromagnetic radiation. Systematics of active microwave cavities operating in high order modes need to be examined theoretically and experimentally. The qualities of low-loss surfaces made of corrosion resistant low cross section materials must be examined.

Lastly, the radiation chemistry of the production of free radicals by highly ionized particles has been given only limited attention by chemical engineers. The high efficiency of fission particles for the production of persistent radiation damage in solids is well known to reactor materials engineers. A systematic examination of the mechanisms of production of metastable species at moderate temperature in both inorganic and organic compounds promises to yield results of interest both to researchers and to applications engineers. Of most immediate concern is the vital need for the production of synthetic high energy content gases or liquids by irradiation of low energy content parent products.

In Summary, Are These Programs Feasible in a Lengthened Time Scale?

The exigiencies of the politics of government-sponsored research are well known to most of us. However basic a piece of research may be, it must nevertheless demonstrate a relationship to a useful product within about five years -- or else! The controlled thermonuclear fusion research program is one of the few surviving exceptions to this general rule. Its survival is no doubt attributable to widely publicized competitive undertakings in the Soviet Union. As a result of this general truism, the research work described above would best be pursued at a scale not requiring expensive, extensive Federal government sponsorship. Fortunately, the University of Missouri is well equipped to undertake this. On its Rolla campus it has an excellent medium power research reactor (Figure 4) within which much of the exploratory work on plasma chemistry could be undertaken. At Columbia an aggressive and innovative engineering program will permit the use of the high flux MURR (Figures 5,6,&7) for studies of electron behavior in a fission-excited gaseous medium in a magnetic field. This program will require a special amendment to the reactor license, since fissile material will need to be irradiated in the experimental volume.

While "break-throughs" can be hoped for, the program outlined should proceed on a time scale of at least two decades, and should entail strong interaction among nuclear engineers, plasma physicists, radiation chemists and materials technologists on all MU campuses. It will, I hope, reveal a truism which lies back of all successful applied science: great inspirations occur to those who accumulate adequate theoretical and experimental background. In a new field of knowledge, this can be built up only by blood, sweat, tears and time!

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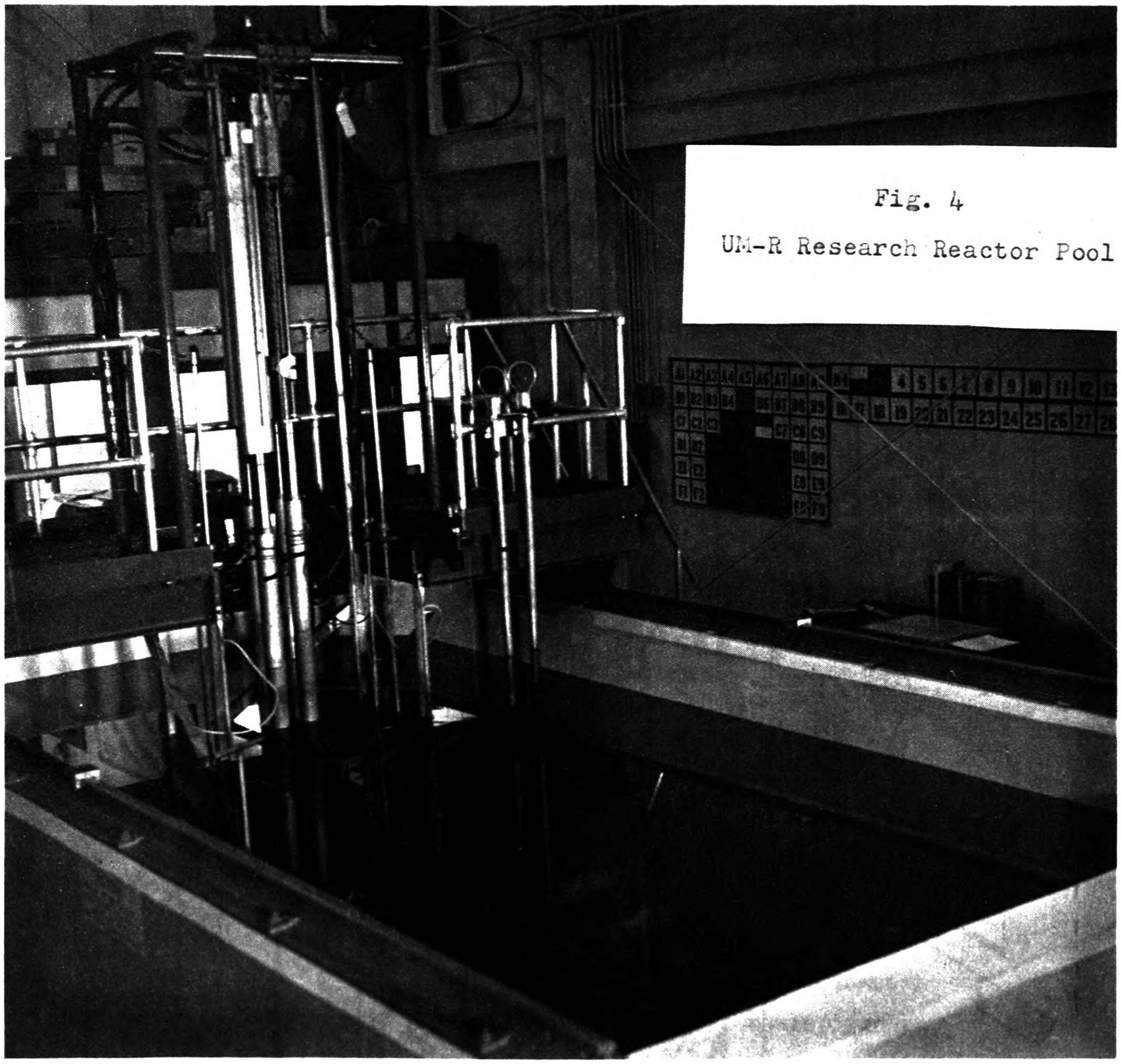


Fig. 4

UM-R Research Reactor Pool

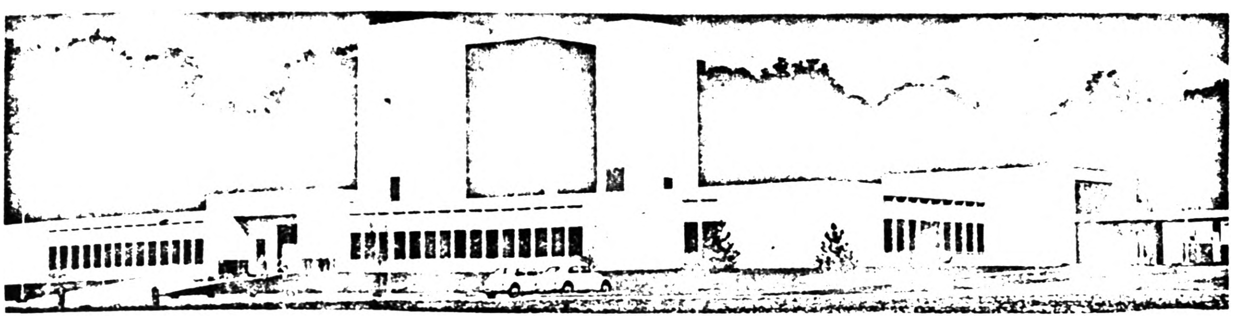


Fig. 5

Outside View, MURR Columbia

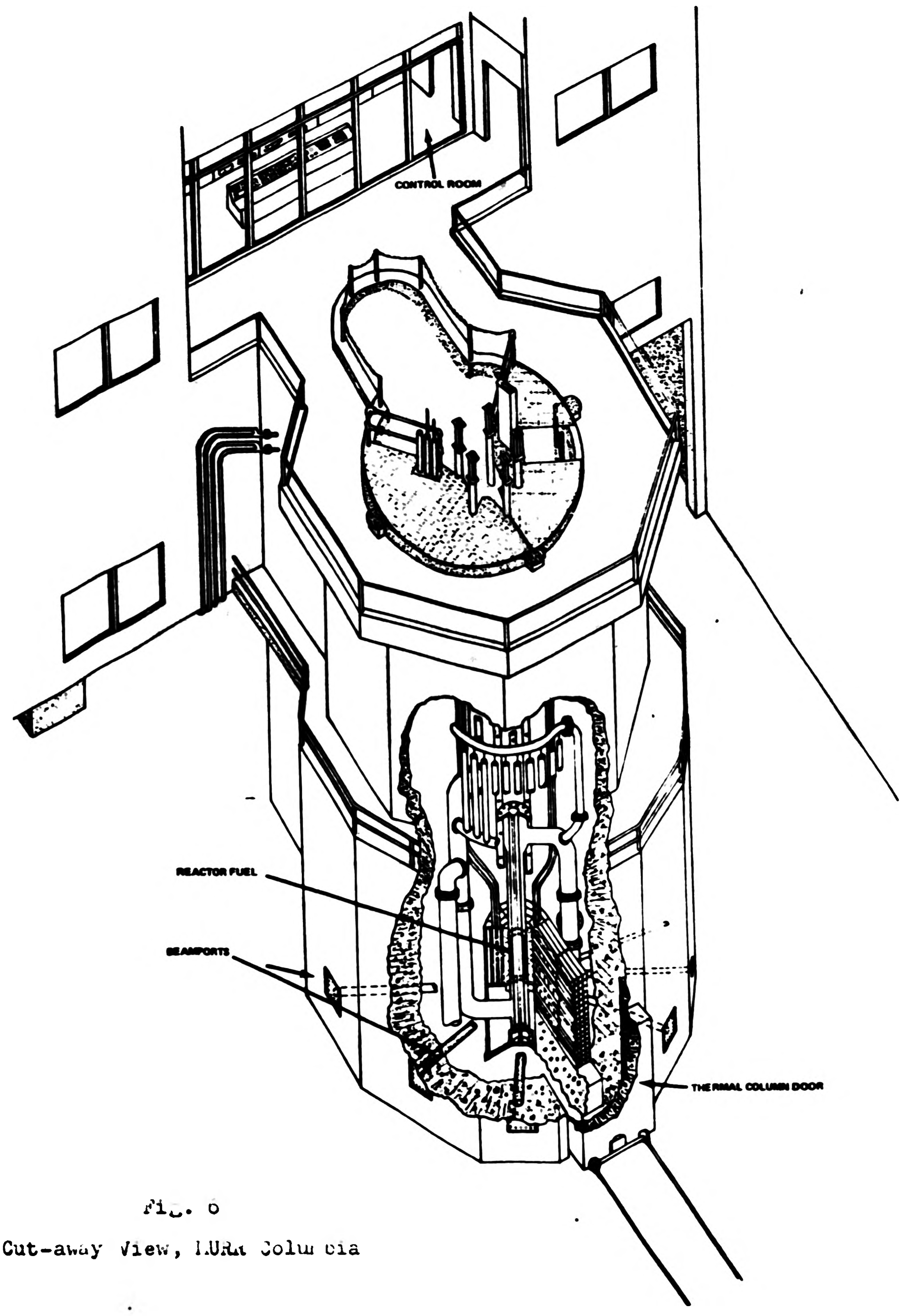


Fig. 6

Cut-away View, MURR Columbia

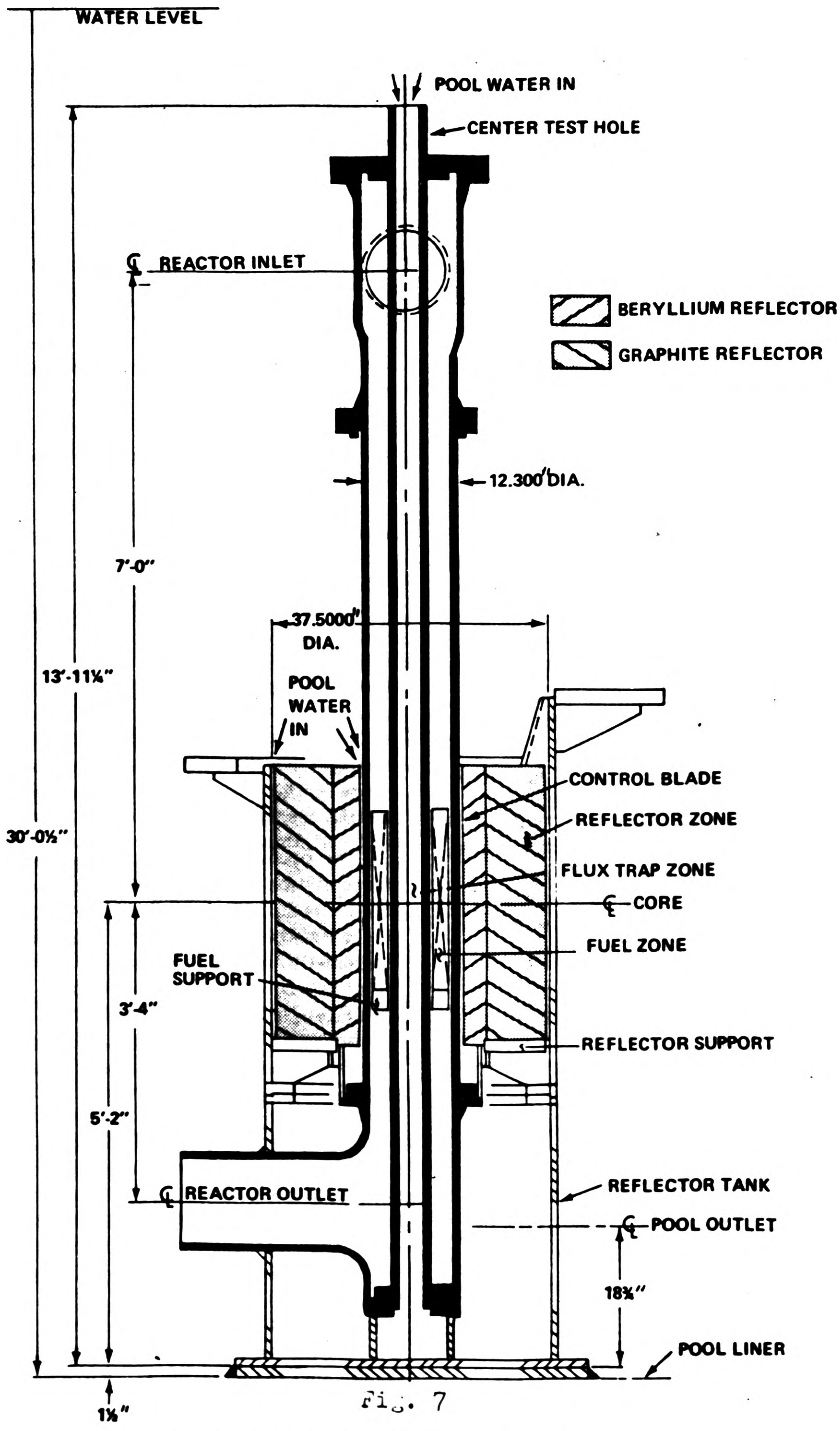


Fig. 7

Section of the Core and Reflector
MURR Columbia

ARE NUCLEAR SHIPMENTS REALLY SAFE?

Presented by:

William A. Brobst
Chief, Transportation Branch
Division of Waste Management and Transportation
U.S. Atomic Energy Commission
Washington, D.C. 20545

Before the:

First Annual UMR-MEC Energy Conference
University of Missouri
Rolla, Missouri 65401

April 24, 1974

ABSTRACT

The transportation of nuclear materials is on the increase. Although nuclear shipments are only a very small fraction of the Nation's hazardous materials shipments, they attract a great deal of public attention. Shipments of spent nuclear fuel and nuclear wastes are a particular concern.

One of the many fears that people have about nuclear energy is the possibility that a nuclear shipment might somehow go awry and cause a serious public hazard. Primarily, they are worried that a shipment of spent reactor fuel or highly radioactive waste could be involved in a serious rail or highway accident and dump its contents all over the countryside.

Is that *really* possible? How safe *are* those shipments? How many are there? What do they look like? Are the packages tested? These and other questions are answered in this paper. Since public risk is the product of the consequences of an accident and its probability, both aspects are presented so that each of us can make up his own mind whether the risk from nuclear shipments is acceptable.

Introduction

We live in a world of hazards. We are surrounded by threats to our health, our welfare, and our economy. Amongst the many hazards we face is the one involving the transportation of hazardous materials. One of the hazardous materials with which we must concern ourselves is nuclear material.

Public safety in the transportation of hazardous materials has been the subject of increasing emphasis. An article in the May 1970 issue of the Reader's Digest stated, "Transportation of hazardous materials on our roads, railroads, and waterways is a major and growing problem. One of every ten trucks rolling toward you on the highway today carries explosives, flammables, or poison. [1]

Questions have arisen in numerous public hearings on nuclear reactor operations with regard to the adequacy of public safety in the transportation of nuclear materials to and from nuclear reactors and fuel reprocessing plants. This paper presents a summarized status report on the potential hazards of shipping those nuclear materials. Since there have been no serious releases of nuclear materials in transportation accidents during the 25-year life of the Atomic Energy Commission, the paper is based on a theoretical analysis of accident risks.

What Is Shipped?

Nuclear power will play an increasingly important role in meeting the Nation's energy requirements. As nuclear power increases, the quantities of nuclear materials which must be shipped will also increase.

The operation of nuclear power reactors will usually require the transportation of three different types of materials to and from reactor facilities. Unirradiated ("cold" or "fresh") nuclear reactor fuel elements are transported from fuel fabricators to the reactor. Irradiated ("spent") fuel elements and nuclear wastes are shipped from reactor facilities to fuel reprocessing plants and to disposal sites. Also, the radioactive products of the spent fuel reprocessing plants consist primarily of recycled nuclear fuel materials shipped to fuel fabricators or processors and both high-level and low-level waste shipped to disposal sites.

Other shipments of radioactive materials are made in support of nuclear power plant operations. For example, uranium concentrate, produced from uranium ore, is shipped from uranium milling plants in the western United States to uranium conversion facilities for conversion of the uranium concentrate to uranium hexafluoride. Uranium hexafluoride is shipped to one of the Atomic Energy Commission (AEC) uranium enrichment facilities. The enriched uranium hexafluoride is then shipped to other plants which convert the material to uranium oxide which is then fabricated into fresh reactor fuel elements.

The Department of Transportation (DOT) has estimated [2] that there are nearly 1,000,000 packages of nuclear materials shipped each year. About 95 percent of the shipments involve small quantities of nuclear isotopes for use in industry, medicine, agriculture, and education. By comparison, the total number of shipments of nuclear materials to and from nuclear power plants in 1971 probably numbered only a few thousand. [3] By the year 2000, however, the numbers of shipments to and from nuclear power plants will probably increase by at least 100 and perhaps as much as 1,000. [4]

Shipments of nuclear materials are not readily distinguishable from shipments of other hazardous materials being transported in routine commerce. They look like ordinary shipments. They are usually handled and loaded in an ordinary manner, using ordinary freight handling equipment. They are transported on a worldwide basis, like other shipments, in the cargo compartment of an airplane, in a closed trailer or railroad boxcar, on "low boys" over highway, or on heavy duty flatcards by rail.

They are not readily distinguishable, but there is a difference. Nuclear materials, like many other materials, have hazardous properties. These properties must be considered in the transportation of nuclear materials–considered from the viewpoints of possible radiation exposure to people, contamination of property, and overall effect on the environment. As a result of the depth of research studies of the hazards and experience in the handling of nuclear materials, their properties are better understood than the hazardous properties of most other hazardous materials being transported in far greater volume.

The packaging requirements for nuclear materials are designed to provide a high degree of protection and safety for personnel and materials, during both normal conditions of transportation and severe accidents.

Principles Of Nuclear Shipment Safety

Protection of the public and the transportation workers from radiation during the shipments of nuclear fuel and waste is achieved by a combination of limitations on both the contents (according to the quantities and types of radioactivity) and the package design. Because shipments move in routine commerce, and on conventional transportation equipment, they are, therefore, subject to normal transportation accident environments [5] just like other nuclear cargo. The shipper has essentially no control over the likelihood of an accident involving his shipment. He does have control over the consequences of accidents by controlling the package design, contents, and external radiation levels. Safety in transportation does not depend upon special handling or special routing.

In the transportation of all types of hazardous materials, there is a difference between potential hazards and realized damage. For hazardous materials, a system of protection is used to reduce the likelihood of the potential hazard from becoming a reality. A highly developed and sophisticated system of protection has evolved for the transportation of nuclear materials. This system is based upon a simple principle–if a package contains enough radioactivity ("Type B" quantity) to present a significant risk of injury or large property loss if released, then the package ("Type B" package) must be designed to retain its contents during severe transportation accidents. [5,6] Lesser quantities ("Type A" quantities) do not require as much protection, but still must be packaged in high quality "Type A" packaging. In addition, all packages (Type A and B) are required to completely retain their contents during normal conditions of transportation.

The basic principles of safety are translated into the Federal Government regulations.

Government Regulations

The transportation of nuclear materials is subject to the regulations of both the DOT [7] and the AEC. [8] The DOT Hazardous Materials Regulations also provide for safety in shipment of other more routinely shipped hazardous materials–materials which are flammable, unstable, poisonous, explosive, or corrosive. The same basic safety standards governing shipments of nuclear materials in the United States are in worldwide use through the regulations of the International Atomic Energy Agency. [9]

In addition, the packages must provide adequate radiation shielding to limit the radiation exposure to transportation workers and the general public. For spent fuel, the package must have heat dissipation characteristics to protect against overheating from radioactive decay heat. For both fresh and spent fuel, package design must also provide nuclear criticality safety under both normal transportation and severe accident conditions.

Package designs are reviewed by the AEC prior to use in order to verify the adequacy of the design parameters. If it appears that the package will, in fact, meet the regulatory requirements, [7,8] the AEC will issue a certificate of approval for the package.

Shipment Information

DOT regulations specify the type of information which must appear on bills of lading and other shipping papers. Packages are required to be labeled appropriately. Warning placards generally must be placed on the transporting vehicle. This puts the carrier and emergency personnel on notice that they are handling shipments of hazardous goods. It alerts them to the fact that applicable state and local regulations and ordinances need to be followed.

Quality Assurance

The adequacy of the package design can be compromised or circumvented by errors which occur during fabrication, maintenance, or use of the package. The person loading and closing the package could make errors. Perhaps one or more bolts could be left out or not properly tightened; a gasket could be misplaced or omitted; a brace or "holddown" piece could be left off. The chances of such an error are limited because of the procedures required by the regulations for examination of the package prior to each shipment, including tests for leak tightness, where necessary. Redundancy of safety features on the package will reduce the consequences of such operational errors, should they occur.

Use of the wrong materials or errors in fabrication also could result in a package failing to function properly during transportation. Adequate quality assurance programs increase the likelihood that such errors would be detected and corrected, prior to use. The regulations [8] impose certain quality assurance requirements on package manufacturers. The shipper is required to determine that each package meets the approved design specifications.

Types of Radioactive Waste

Different types of radiation have different penetrating abilities. For example, alpha particles have a very short range in air and cannot even penetrate a piece of paper; beta particles travel over a larger distance, but can still be shielded completely by light, low-density materials such as aluminum; gamma rays require thicker or more dense shielding materials such as lead and steel. The chief hazard to human beings from alpha materials would be from deposition of the materials within the body, so special care must be taken in containment of the alpha wastes. Beta-gamma wastes also require maintenance of container shielding.

There are several different types of materials which may be found in nuclear wastes. Nuclear wastes which are shipped around the country to various processing, storage, or burial sites fall into three general categories: (1) low specific activity (LSA) wastes; (2) high-level wastes; and (3) other wastes.

Low specific activity wastes are those which contain such low concentrations or quantities of radioactivity that they do not present any significant environmental hazards. Even if they were released from their packages in a transportation accident, they would not present much hazard to the public. Like any other freight spilled at the scene of an accident, they would have to be cleaned up because of their nuisance value. Under U.S. and international regulations, they require only normal industrial packaging for shipment and require no special rail cars or other transport vehicles. LSA wastes may include such things as residues or solutions from chemical processing; building rubble, metal, wood, and fabric scrap; glassware, paper, and plastic; solid or liquid plant waste, sludges, and acids; and slightly contaminated equipment or objects.

Alpha wastes, high-level wastes, and other wastes contain sufficiently large amounts of radioactivity that they have a significant potential for injury or property damage if released to the environment during a transportation accident. For that reason, DOT and AEC regulations require that they be packaged such that, even in the event of a severe transportation accident, there would be no significant release of radioactive materials outside of the containers. The packages (Type B packages) must then be strong enough to withstand the types of impact and puncture forces and fire effects which are often encountered in severe accidents.

High-level wastes are those solidified wastes from the reprocessing of highly irradiated nuclear reactor fuels. These wastes have such a high radioactive content of long-lived isotopes that they require long-term storage in isolation and essentially perpetual surveillance of the storage sites. The radiation level is high enough to produce considerable heat, and the material must be heavily shielded. The most common type of high-level waste shipments will be the solidified (process) waste from the nuclear fuel reprocessing plants. Only solid materials of this type will be shipped to waste storage sites. Shipments of high-level liquid wastes are not presently allowed by the DOT, and are not practical due to problems in designing safe containers for bulk shipment of such liquids.

Alpha wastes usually consist of materials which are contaminated with alpha radiation emitters such as plutonium or other transuranium nuclides. They have very low levels of penetrating gamma radiation and so do not require heavy shielding. Alpha emitters have the potential for causing contamination of objects or people if released from their packages. If the amount of nuclear material exceeds certain levels of concentration, the alpha wastes must be packaged in Type B packages, but of a different type than the very heavy high-level waste packages. The emphasis in packaging for transportation is containment, with several containment barriers provided in the packaging system.

Other wastes are predominantly of the beta-gamma type (e.g., fission product, industrial isotopes) which usually requires some shielding material as a part of the package. This waste may also be a combination of LSA, alpha, and beta-gamma types. Beta-gamma waste includes such things as irradiated reactor structural components, heavily contaminated objects, concentrated solidified sludges or evaporator bottoms, and nonrecoverable radioactive fuel scrap. Because of the presence of considerable quantities of nuclear material, packages of these materials must also be capable of resisting severe accident.

Package Integrity

Before a specific type of Type A package is approved by the AEC for shipment of nuclear materials, it must be capable of withstanding, without leakage, a series of "torture test" which produce damage conditions comparable to the actual damage a package might encounter in a hypothetical severe transportation accident. The accident damage test sequence specified in the DOT and AEC regulations includes a 30-foot fall onto a solid unyielding surface, followed by a 40-inch drop onto a 6-inch diameter piston, followed by exposure for 30 minutes to a 1475°F fire. A water immersion test is also required.

This test sequence represents the type of damage which might occur to a package in a high-speed truck accident or train derailment, causing the package to impact on a hard surface (such as a bridge abutment) and then to smash through wreckage or onto rocks, and then to be directly involved in a 2-4 hour cargo fire, and then to roll down into a river! The regulations therefore offer a very high degree of assurance that a package will not breach under severe accident conditions.

A specific safety analysis report must be prepared for each package type and evaluated by the AEC before use. Only if the packaging has successfully passed such rigorous evaluations does the DOT authorize its use. At present, there are several hundred different types of radioactive material package designs that have been authorized, ranging in size from small packages weighing a few pounds to massive casks weighing over 100 tons.

Packaging Methods

Fresh Fuel. A "typical" package for a "typical" [16] light water reactor fuel is a cradle assembly consisting of a rigid beam or "strongback" and a clamping assembly which holds a few fuel elements firmly to the strongback. The strongback is shock-mounted to a steel outer shell. Fresh fuel elements might also be shipped in steel boxes which are positioned in an outer wooden box by a cushioning material. These packages, also with a few fuel elements inside, would be about 2 to 3 feet in diameter or cross section, and about 17 feet long. They would weigh from 1,000 to 9,000 pounds. Typical containers are shown in Figures 1 and 2.

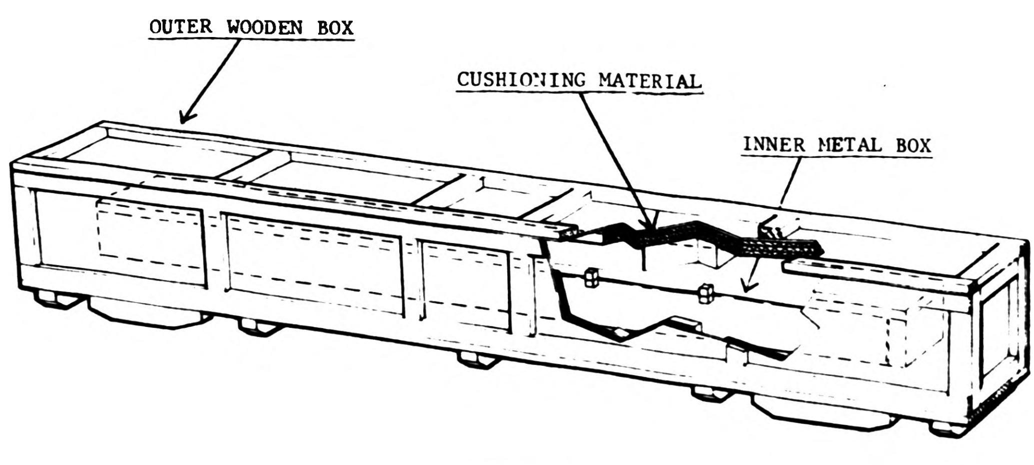
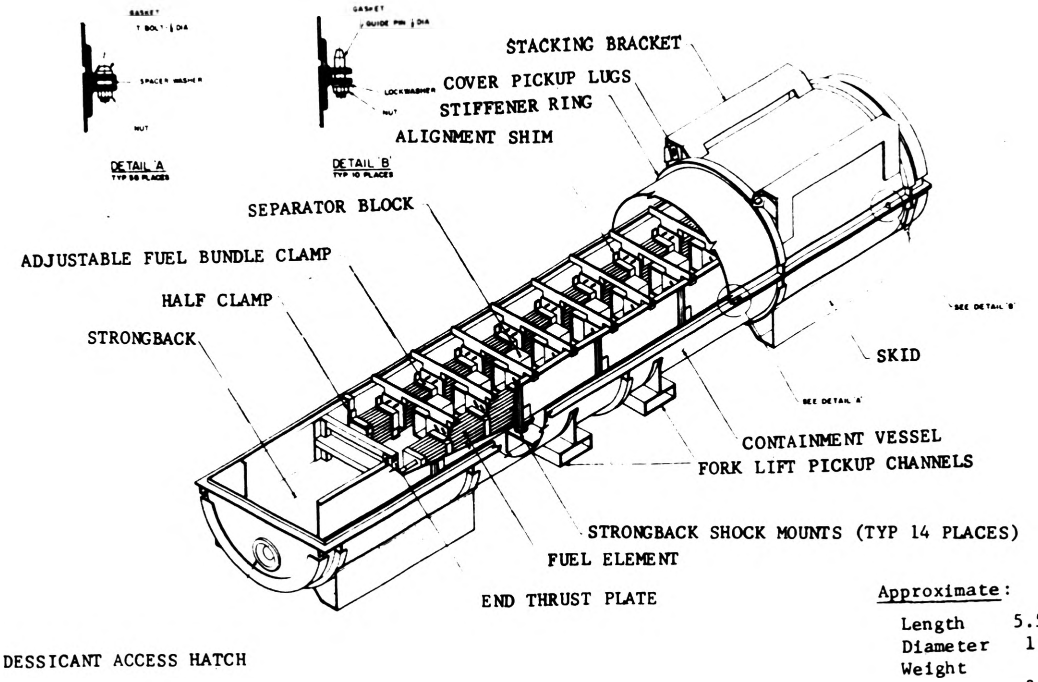


FIGURE 1
BWR FUEL ELEMENT SHIPPING CONTAINER (GE MODEL RA-1)



Approximate:

Length	5.5 meters
Diameter	1 meter
Weight	
empty	2 tons
loaded	3.7 tons

FIGURE 2
PWR FUEL ELEMENT SHIPPING CONTAINER

Spent Fuel. Because irradiated fuel elements are highly radioactive, their containers must be very heavily shielded. A typical "cask" used for shipping spent fuel would weigh between 20 and 75 tons. It would be constructed of thick steel walls filled with a dense shielding material such as lead, tungsten, or depleted uranium. Each cask would carry 1-7 PWR elements, or 2-18 BWR elements. The casks would be generally cylindrical in shape, and perhaps 5 feet in diameter and 15 to 18 feet long. A recently designed cask of this type is shown in Figures 3 and 4.

The cask must not only provide radiation shielding, but must also provide the means to dissipate the large amount of heat (perhaps 75,000 BTU/hr) produced by radioactive decay. Water is usually used in the central cavity as a heat medium or primary coolant to transfer the decay heat from the fuel elements to the body of the cask. The heat is usually dissipated by natural processes to the air through fins on the surface of the cask. For some of the larger casks, air may be forced over the fins by blowers to increase the cooling. In other casks, heat exchanges with cooling coils running into the body of the cask literally pumps the heat out and into the atmosphere. Reliable, redundant systems are used where such mechanical systems are relied upon to ensure adequate cooling. [12]

High-Level Nuclear Waste. At the present time, the AEC is planning on long-term storage of all high-level wastes from commercial fuel reprocessing plants at a Federal waste repository or engineered storage facility. Some intermediate level fission product wastes may be further treated for separation into high-level and low-level components, the former of which would be destined for shipment to a Federal storage facility, and the latter for shipment to commercial burial facilities.

Shipping containers for high-level waste shipments will be very similar in their basic design to the shielded casks routinely used to ship spent fuel assemblies from a nuclear power plant to a fuel

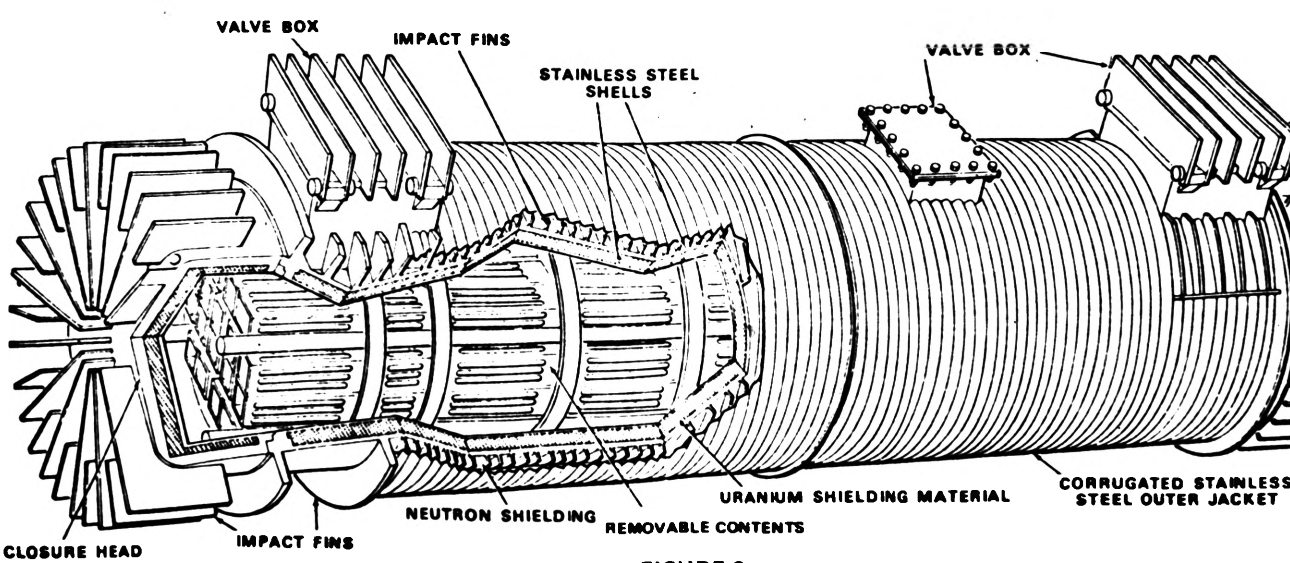


FIGURE 3
SHIPPING CASK

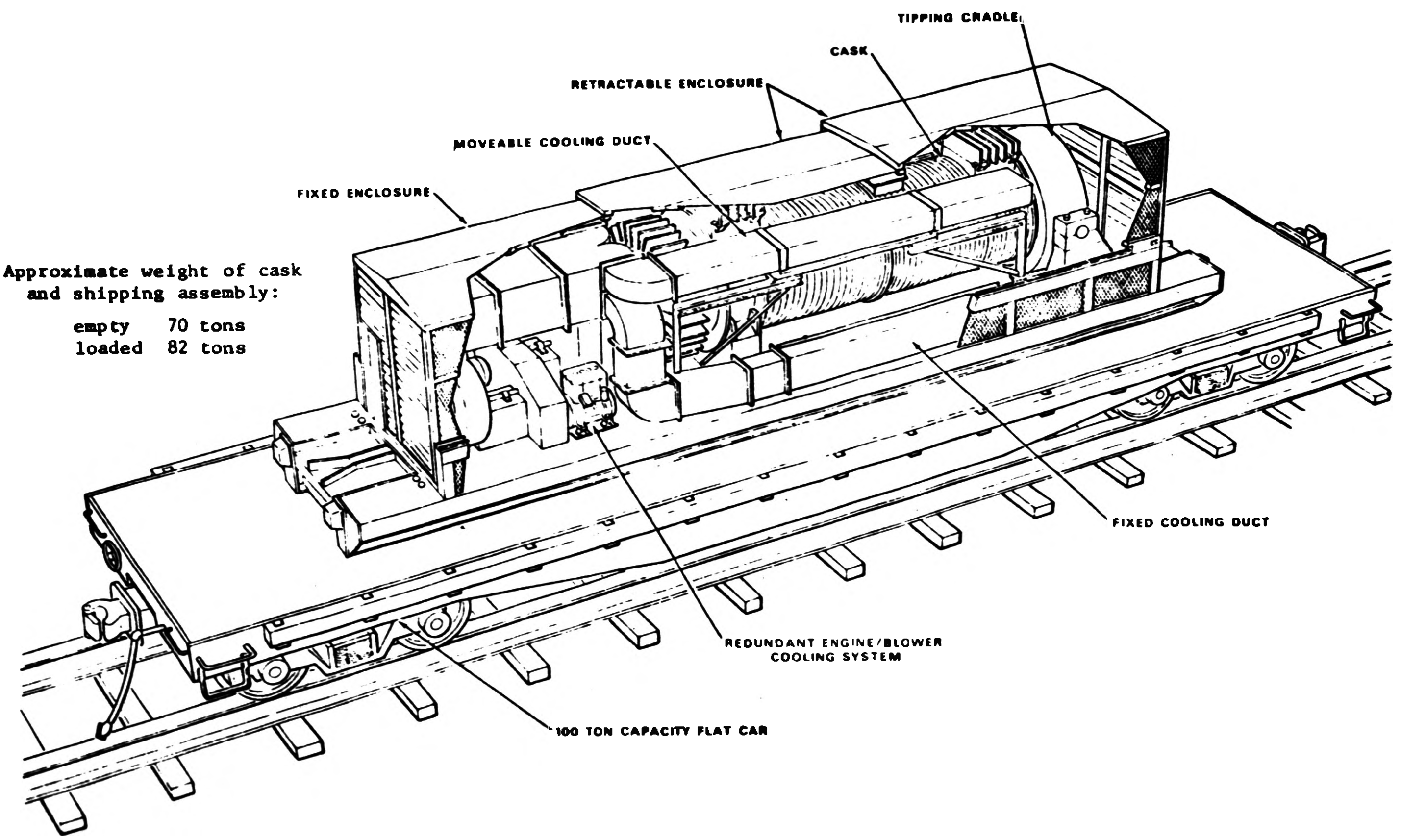


FIGURE 4
IRRADIATED FUEL CASK ON RAIL CAR

reprocessing site. Spent fuel is very similar in its overall shipping characteristics to canisters of high-level waste in that it is highly radioactive and generates considerable heat. In both cases, the shipping casks would be essentially the same type–large steel casks, lined with lead, steel or uranium. The high-level waste actually will be in a burial capsule or canister within the outer shielded cask. The waste is inert, immobile, solid material which is nonexplosive, noncombustible, and cannot turn to gaseous form and become airborne. These high-level waste casks would be transported by rail on conventional heavy duty flat cars. Highway load limits, rather than safety reasons, will restrict highway shipments.

No detailed cash designs have yet been submitted by industry for AEC approval, since shipments to a storage facility will probably not begin until the early 1980's. [18]

Low-Level Nuclear Waste. Under the DOT regulations, [7] low level solid waste is packaged depending on the amount of radioactivity in the package. Typically, the waste is solidified in a mixture of vermiculite and cement in Type A steel drums. When filled, the individual drums weigh between 500 and 800 pounds. If the drums contain Type B quantities of waste, the drums would require the addition of a Type B "overpack" (i.e., protective outer packaging) to provide accident protection for the drums. Low specific activity wastes or Type A quantities of waste may be shipped in drums without protective overpacks.

Alpha Waste. Alpha waste is shipped either in a large accident proof box or in a bundle of 55-gallon drums encased in some sort of outer protective container to protect such materials from impact and fire. Special railroad cars already constructed have been used to transport the solid alpha wastes to a storage facility. Other methods and modes of transportation may be used in the future.

Number of Shipments

Pattern of Shipments. Shipments would be nationwide, with the predominance in the east. Reactor locations as of Dec. 31, 1973, are shown on Figure 5. Fuel processing plants are located in New York, Illinois, and South Carolina. Fuel fabricators are scattered throughout the east. Commercial waste burial sites are in New York, Tennessee, Illinois, Nevada, Washington, and Kentucky.

Fresh Fuel. Each year, on the average, about 1/3 to 1/5 of the fuel in a reactor is replaced with fresh fuel. Fresh fuel is usually shipped by truck, with 6 to 16 packages per truck. About 6 truckloads of fresh fuel elements would be shipped to a reactor each year. For 100 reactors, that's 600 truckloads per year nationwide.

Spent Fuel. At present, all shipments of spent fuel are made under "exclusive use" arrangement, by truck or rail. Some barge shipments may be made in the future. There would be about 10 rail shipments or 40 truck shipments annually from each reactor to a fuel reprocessing plant. For 100 reactors, that's 1,000 rail shipments or 4,000 truck shipments per year.

Radioactive Waste from Reactors. About 4,000 cubic feet of low level waste per year would be shipped from a BWR, and about 1,000 cubic feet per year from a PWR. Most of the shipments would be made by truck. About 2,000 drums of radioactive waste would be shipped, with about 40 to 50 drums per truckload, for about 45 truckloads per year for a BWR. For a PWR, there would be about 500 drums and 10 truckloads per year.

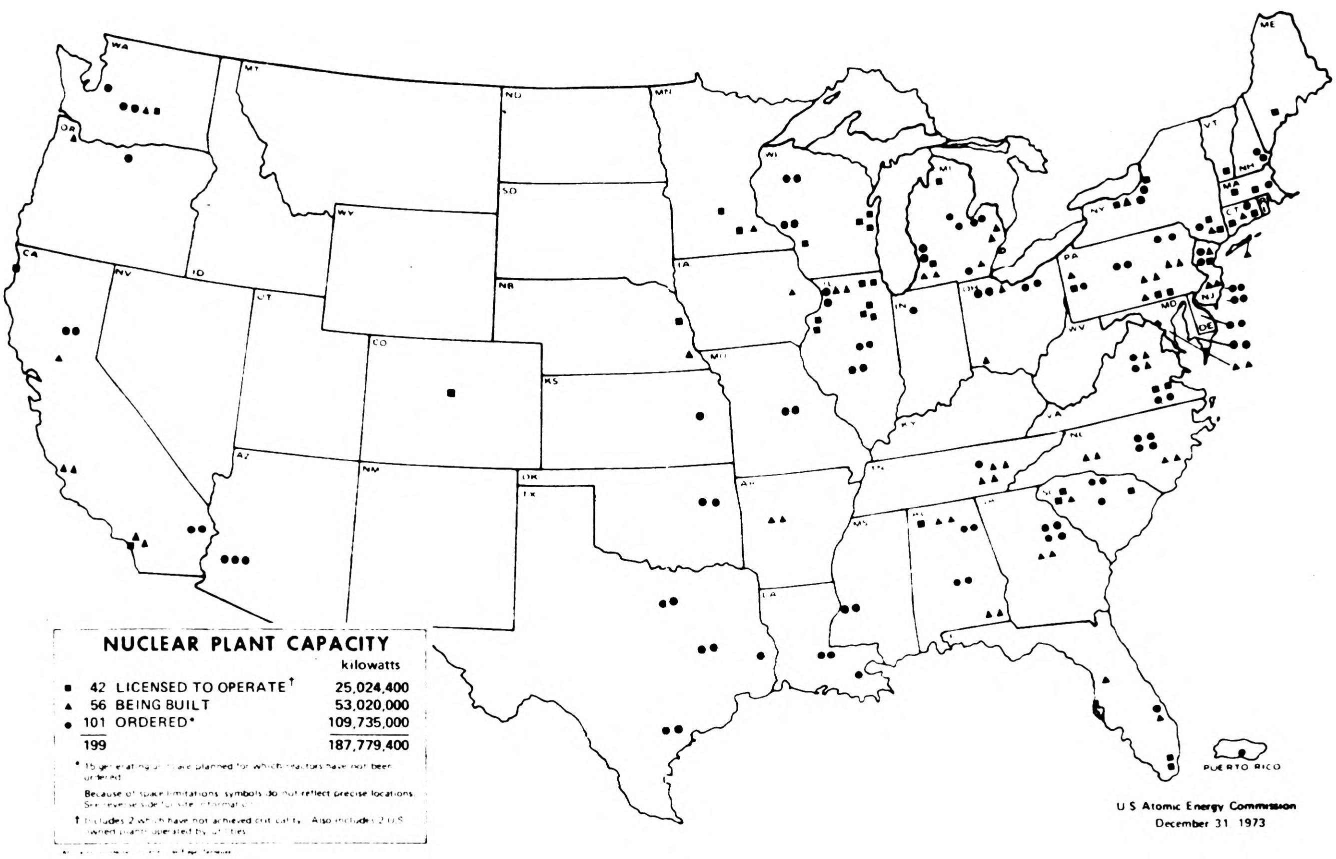


FIGURE 5
NUCLEAR POWER REACTORS IN THE UNITED STATES

Radioactive Waste from Reprocessing Plants

High-Level Waste. The first shipments of high-level waste from reprocessing plants are not expected until about 1983. By 1985, there will be about 25 shipments a year. By 2000, there will be 260 shipments per year, for the three reprocessing plants. [18]

Low-Level Waste. Each reprocessing plant is expected to produce about 20,000 cubic feet of low level waste per year. There would be about 700 truckloads each year for three reprocessing plants.

Alpha Waste. Each reprocessing plant is expected to produce about 5,000 cubic feet of alpha waste per year. This would be about 30 rail carloads or 150 truckloads each year for three reprocessing plants.

Accidents

Accidents occur in a range of frequency and severity. Most accidents occur at low vehicle speeds, but the severity of accidents is greater at higher vehicle speeds. Most severe accidents generally involve some combination of impact, puncture, and fire effects. Even if the hazardous nature of the cargo is not a factor, accidents often result in injury, death, and cargo or other property loss due to common causes.

Truck Accidents. In 1969, motor carriers reported [13] a total of about 39,000 accidents, 20,000 injuries, and 1,500 deaths. The injury rate is about 0.5 injuries per accident, and the death rate is about 0.03 deaths per accident. The accident rate for hazardous materials shipments was about 1.7 accidents per million truck miles.

Assuming 100,000 truck miles per year of transportation for each nuclear power plant, there would be about 0.09 injuries per year and 0.005 deaths per year per reactor. Those deaths and injuries would be from conventional or common causes not related to the radioactive nature of the cargo.

The nonnuclear property damage rate is about $2,000 per truck accident. With 100,000 truck miles per year per reactor, this would be an average loss of about $300 per year per reactor due to nonnuclear causes.

Rail Accidents. In 1969, the rail industry reported [14] about 8,500 accidents, 23,000 injuries, and 2,300 fatalities. The accident rate for rail accidents was about 1.4 accidents per million car miles.

There were about 2.7 injuries per accident and about 0.27 deaths per accident. Assuming about 15,000 rail car miles per year per reactor, there would be about 0.06 injuries and 0.006 deaths per year per reactor, from conventional and common causes.

Nuclear Materials. To date, there have been no injuries or deaths of radiological nature due to the transportation of nuclear materials. [5] There have been a few cases of truck drivers being killed or injured as a result of a collision or overturn of vehicles carrying nuclear materials. In none of these cases, however, was there any release of nuclear materials from Type B packages. [2]

In recent years, DOT has recorded [2] an average of 40 to 50 incidents per year involving the transportation of nuclear materials. Almost all of these incidents involved Type A or exempt packages. In about 2/3 of these cases, there was no nuclear material released from the packages. In a few percent of the cases, there was significant contamination requiring cleanup, with cleanup costs running into the thousands of dollars.

Accident Risk

Principle of Risk. The significance of radiological hazards during transportation of nuclear materials can be properly evaluated only by considering together the consequences of accidents and the probabilities of those accidents. One could compare the risks of transportation of nuclear materials in several ways. For example, one might compare the probabilities of shipment accidents;[15,16] one might compare the average cost of accidents by each mode of transportation; one might compare direct transportation costs, which includes insurance premiums. However, all of these partial measures for comparing risk may be combined into a single contingency risk cost factor which is the product of the probability of experiencing an accident involving nuclear materials and the probable cost of such an accident if it occurs. In late 1972, the AEC completed a study [17] of this type of comparison for nuclear reactor power plant transportation.

Accident Records. In estimating the radiation risk from accidents involving shipments of nuclear materials to and from nuclear power plants, one must consider: (1) the frequency and the severity of accidents; (2) the likelihood of package damage or failure; (3) the nature, amount, and consequences of releases of radioactivity during an accident; and (4) the capacity of coping with such releases.

The environmental effects [5] which might occur in transporting nuclear fuel and solid wastes resulting from the operation of a "typical" power reactor has been evaluated. [17] The risk analysis covers transportation of: (1) fresh fuel from a fabrication plant to a reactor by truck; (2) spent fuel from a reactor to a fuel reprocessing plant by truck, rail or barge; and (3) solid wastes from a reactor to a radioactive burial site by truck or rail. The range of known distances between various sites must be considered. Estimates may be made of radiation effects on the environment under normal conditions of transportation and for credible severe accidents. The potential accidents may be analyzed in terms of severity and predicted damage, and the probable consequences of releases. Finally, by combining the probabilities of accidents with the consequences, the overall risk of transportation accidents may be estimated.

Normal Conditions. According to the AEC analysis, [17] truck drivers and freight handlers would normally receive an average of about 0.2 to 0.3 millirem per shipment of fresh fuel. No member of the general public is likely to receive more than about 0.005 millirem per shipment. Most of the general public's exposure would be nonrepetitive in that no single member of the general public would be exposed to those dose levels more than a few times per year. The most that any one member of the general public might get during a year would then be perhaps 0.01 millirem or about 1/50,000 of his annual permissible exposure.

For spent fuel shipments and radioactive waste, each truck driver could receive as much as 30 millirem per shipment. A few members of the general public could receive as much as one millirem per shipment, or about 1/500 of his annual permissible exposure.

Accident Probabilities

A study of accident probabilities [16] showed that the frequency of severe accidents for both truck and rail shipments is about one for each one hundred million truck miles or rail car miles. The probability of extremely severe accidents is about 100,000 times less. Considering the total number of truck miles or rail car miles involved per reactor and estimating the predicted accident response of packages, the study [16] shows that the predicted likelihood of serious leakage arising from accidents involving packages of nuclear materials to or from a nuclear power plant in any one year is about one in five million. By comparison, the likelihood of serious injury due to an automobile accident per person per year is about one in 500.

The study [16] also shows that, in the transportation of nuclear materials, the probability of injury or death due to common accident causes is at least 100,000,000 times greater than the probability of injury or death due to radiological consequences. Correspondingly, the total property and cleanup loss from nonnuclear common causes in transportation accidents is expected to be about $300, or about 2,500 times greater than the probable losses from radiological contamination. The total expected average loss from contamination in transportation per reactor year is about 12 cents.

Conclusion

On the basis of the studies referred to, it appears that the probability of death, injury, or massive property loss due to transportation of radioactive materials is (1) determinable, (2) not zero, and (3) very small. In projecting the total accident probability for transportation of radioactive materials to and from nuclear power plants, it seems obvious that the radiological consequences of the total accident spectrum will be several orders of magnitude below the more common nonradiological causes. It further appears that radiation doses to transportation workers and the general public during the normal course of transportation will be limited to a small fraction of the total permissible annual dose, and then only to an extremely small segment of the population. The various studies show clearly that the likelihood of a catastrophic nuclear transport accident is so infinitesimal that, for all practical purposes, it can be confidently said that one will never happen.

The risk is small, but is it acceptable? And to whom? Modern life confronts people with a multitude of risks. We don't live in a riskless society, nor could modern technological societies exist on that basis. Each person has his own idea of what risks are acceptable to him. The public apparently judges the convenience of air travel to be worth the risk that results in 200 fatalities per year; the convenience of driving an automobile is considered worth much higher levels of risk. Some people are afraid of airplanes but ride motorcycles. Sometimes the public judgments are not especially rational. About 49 million Americans continue to smoke cigarettes despite the clear warning of risk to their health printed on each package. Others smoke heavily but take a vitamin pill every day to stay healthy. Many people are afraid of the potential hazards of nuclear power, but risk their necks every day in the hazardous reality of highway travel. Some say that risks which they choose to accept are acceptable, but risks which others force on them are not. In each case, the acceptability is most likely to be based on subjective emotional reactions—"gut" feelings—rather than a logical analysis of accident data or other actual experience. Few of us are afraid of being bitten by a venomous snake, or being attacked by a rhinocerous, in the middle of Washington, D.C., but that probability is also (1) determinable, (2) not zero, and (3) very small.

Certainly laws and regulations themselves will not guarantee risk-free transportation. We are all aware of the potential risks in nuclear matters if safety is not given the very close attention it deserves. Transportation accidents and their potential effects on shipping containers have been well studied. These studies continue. It is precisely because of this perceived risk that the AEC has always imposed stringent and overlapping protective measures in their concept of "defense in depth." However, one cannot claim "assurance" as an absolute. No safety system can nor should it be expected to guarantee complete safety of a few individuals who by very exceptional circumstances, peculiar habits, unusual customs, extreme deviations from the typical individual get into difficulties.

Even the normal industrial safety limits for a variety of hazardous stresses provide only *reasonable* protection for typical workers, and no more than that.

We tend to react to the problem of risk by making choices based on the magnitude of the risk, *as we perceive it,* and the benefits to be gained from accepting the risk.

The National Academy of Sciences has stated, "Whether we regard a risk as acceptable or not depends on how avoidable it is, and how it compares with the risks of alternative options and those normally accepted by industry." As a result of the studies which have been done, it is the AEC's opinion [18]that, with regard to nuclear shipments:

a. We have enough facts and figures on the hazards to allow a more objective evaluation of the risk acceptability than we might derive solely from "gut" feelings.
b. The risk of public catastrophe has been eliminated by strict standards, engineering design safety, and operational care. Whatever the consequences of an accident are, the public hazard will be manageable, and the nuclear effects will be small compared to the nonnuclear effects.
c. The long-term public burden of *not* transporting nuclear materials is likely to be higher than the risks of carefully controlled transportation, considering the various options available.
d. The likelihood of death, injury, or serious property damage from the nuclear aspects of nuclear transportation is thousands of times less than the likelihood of death, injury, or serious property damage from more common hazards, such as automobile accidents, boating accidents, accidental poisoning, gunshot wounds, fires, or even falls—all things which we *can* control, but apparently have accepted as a way of life without much public support for reduction of risk.

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RADIATION TESTING UNDER SIMULATED LOCA CONDITIONS

By

K. G. Mayhan, D. R. Edwards & W. F. Oberbeck
University of Missouri-Rolla

J. F. Montle
Carboline Co., St. Louis, Missouri

The purpose of this evaluation is to gather data to determine whether or not radiation during a simulated Loss of Coolant Accident would have any effect upon the coatings being used. Because of the concern in industry regarding the safety of nuclear power generating stations and the strong actions of the various environmentalist clubs and agencies clubs and agencies, the utilities have been required to prove the safety of the power facilities to extraordinary degrees before licensing can be obtained to operate. One of the areas regarding the safety is the necessity of proving that the coatings will remain intact during a Loss of Coolant Accident, which could occur if the main steamline were to rupture. We have designed and built apparatus to test the performance of coatings under the conditions that might exist under such an accident criteria in order to assure ourselves and the AEC in the various utilities that the coatings currently being used or proposed will be adequate for this service.

Since under these conditions the coatings would also be exposed to some radiation, the question has arisen whether or not the radiation will have any effect upon the coating during this accident condition. Tests have been run showing that radiation before or after an accident condition has no effect on the performance, but because of the difficulty in testing, little work has been done with simultaneous loss of collant and radiation. The problem is further compounded by the variety of water chemistries that are involved with various reactor designs, and the fact that many of the time-temperature criteria are so vastly different. Preliminary test results will be reported.

LOCATING NUCLEAR POWER PLANTS UNDERGROUND

FRANK M. SCOTT HARZA ENGINEERING COMPANY CHICAGO, ILLINOIS

ABSTRACT

This paper reviews some of the questions that have been asked by experts and others as to why nuclear power plants are not located or placed underground. While the safeguards and present designs make such installations unnecessary, there are some definite advantages that warrant the additional cost involved. First of all, such an arrangement does satisfy the psychological concern of a number of people and, in so doing, might gain the acceptance of the public so that such plants could be constructed in urban areas of load centers. The results of these studies are presented and some of the requirements necessary for underground installations described, including rock conditions, depth of facilities, and economics.

INTRODUCTION

The question has been raised by a number of people as to why nuclear power plants are not located underground. The obvious answer, of course, is that placing such an installation underground does add to the cost of the facility, but it does have some advantages that will be discussed in this paper. I would like to stress that I am not implying that such plants are unsafe constructed as they are on the surface. The procedures and criteria established by the The Atomic Energy Commission, perhaps, make these installations safer than any other plant or facility.

Locating or placing a nuclear power plant underground does satisfy the psychological concerns of some of the people and, consequently, might be the means that will allow the location of such facilities near load centers and urban areas. Such installations also provide additional protection from sabotage, falling aircraft, missiles, and elements such as tornadoes and hurricanes. Locating power plants near load centers also reduces the transmission costs which, in many cases, might have to be underground, and if so, this in itself can more than offset the additional cost involved.

As Mr. Roddis of Consolidated Edison pointed out in a talk entitled "Metropolitan Siting of Nuclear Power Plants" presented to the IAEA Symposium on Environmental Aspects of Nuclear Power Stations in August, 1970, at the United Nations, the cost cited to bring 1,000 Mwe in by underground transmission 25 miles into the load center would be $180 more per kilowatt than an in-city site.

There are a number of areas that are more susceptible to seismic disturbances and in such areas placing a nuclear power plant underground does increase the ability of the facility to withstand seismic shock. Although the analyses of such disturbances are complex, the stresses caused from such shocks are frequently a function of the height of the structures above rock foundations. Rizzo 1/ indicated that underground rock caverns should have seismic accelerations half that of those experienced on the surface.

While the shielding now provided on nuclear power plants is most adequate, placing the reactors in rock chambers provides natural biological shielding way in excess of the requirements. Underground installations located in solid rock also provide an excellent answer as to how to decommission nuclear plants in the future. The same conditions apply and are available in the unlikely event of a serious accident, as the station can be arranged to be flooded and sealed if the need would arise.

Placing facilities underground is not a new idea, and as Mr. Sorensen brought out in his paper "A Fourth Dimension for Urban Environments," 2/ the trend in the future may be more from the highrise building to underground installations. Most of you are familiar with the use of underground caverns and tunnels for the storage of energy, i.e., oil, gas and water. In the field of transportation, subways have been used for years around the world and the storage of meat and other foods have also been in underground facilities.

There have been a number of papers and studies presented and conducted involving the placement of nuclear power plants underground. A review of some of these studies was presented by Mr. F. C. Olds in Power Engineering in October, 1971. 3/ Mr. Harza also discussed this in a paper at the Annual Meeting of the ASCE in October, 1969 4/ and reviewed some of the installations outside of the U.S. I particularly want to give credit to Mr. Rogers of Harza Engineering Company for the studies he conducted 5/. Since I worked with Mr. Rogers for several years before he elected to take early retirement in 1973, I am using some of the information he developed and presented at the 1971 American Power Conference and published in the October, 1971 Bulletin of The Atomic Scientists. He also conducted a seminar on Underground Siting of Nuclear Power Plants at Oak Ridge on September, 1971.

While there have been many studies, there seem to be only four underground nuclear power plants, to my knowledge, that have been actually constructed. All of these were in Europe. These have been quite small and I understand the one in Lucerne, Switzerland of 30 Mwt, which was a gas-cooled heavy water experimental plant has been decommissioned. This was after a pressure tube rupture occurred in 1969. A larger installation located in the side of a mountain in the Meuse Valley in France is a PWR now rated at 275 Mwe.

A good current summary of the four nuclear reactors placed underground in

Europe; namely, Lucerne Station and the Chooz Plant (Meuse Valley) mentioned above, the 25 Mwt plant in Halden, Norway and the 70 Mwt (70 Mwt used for central heating) plant in Agerta, Sweden, was outlined by R. K. Dodds 6/ in a February, 1974 Foundation Sciences Newsletter. The largest one that I have heard about was a 1200 Mwt plant, which was reported to be considered to be installed underground near a populated area of 500,000 people in Germany, but to the best of my knowledge, this has not gone ahead to date.

For many years underground hydroelectric power plants have been constructed and, in many cases, are on a scale that would be similar to installing nuclear reactors underground; such as a 700 megawatt hydroelectric power plant that is 2,100 feet underground in Colombia. Figure 1 shows a list of underground hydroelectric power plants that have been constructed or are planned by the Harza Engineering Company.

Type of Plant and Arrangement

The studies made by Harza have been based on placing two 1,100 megawatt units underground. We have considered primarily the BWR and PWR, but there is no reason why the HTGR could not be also installed underground. So we would have a specific base and dimensions our studies utilized the BWR, but another type could have been used just as well. For ease in discussing costs, this paper will review some of our findings for two units rated 1,100 megawatts. These costs are based on placing the entire conventional plant underground, including all the conventional shielding used on the surface. Three arrangements were considered. One was to place the two reactors underground with the turbine/generators, radwaste and other facilities on the surface. The second arrangement was to place the reactors underground but with the turbine/generator and other facilities in a pit below the surface of the ground. The third arrangement was to place all of the facilities, including the reactors and turbine/generators, underground. These three arrangements are shown on Figure 2.

Site Requirements

Some of the requirements that must be considered before placing a nuclear power plant underground are the rock conditions in a given area, depths involved and water availability. First of all, there must be suitable and competent rock formations in any area where the plant is to be located. As far as the depth is considered, for biological shielding only 10 to 20 feet would be required. However, to provide structural integrity of an arch above the chamber it would require approximately 100 feet of solid rock. This would also withstand the design pressures of 45 to 60 psi. To insure that the groundwater seepage is inward to the chamber and would not be contaminated by the design overpressures, this would require the roof to be 150 feet to 250 feet below the groundwater table.

Although, in most cases, there would be no problem with groundwater, there is always a possibility in some areas that in the event of an extended dry spell the seepage into the chambers would completely drain the groundwater above the chamber,

NAME	LOCATION	YEAR INITIAL OPERATION	CAPACITY (MW)	NO. UNITS	HEAD (FEET)	DIMENSIONS OF MAIN CAVERN (FEET) L	W	H	HARZA SERVICES PLANNING	DESIGN	RESIDENT ENGINEERING
5 de Noviembre (Guayabo)	Lempa River, El Salvador	1954	81.4	5	161	235	43	66	X	X	X
Ambuklao	Agno River, Philippines	1956	75.0	3	506	260	45	70	X	X	X
Maithon	Barakar River, India	1958	60.0	3	128	235	45	66	--	X1/	X1/
Guatape	Nare River, Colombia	1971	132.0	2	2640	300	55	100	--	X2/	--
Lower Tachien	Tachia River, Taiwan	1971	360.0	4	902	295	[illegible]	115	X1/	X1/	X1/
Montezuma Pumped Storage	Gila River, Indian Res., Arizona	Pending3/	500.0	4	1640	300	72	120	X	--	--
Stony Creek Pumped Storage	Stony Creek, Pennsylvania	Pending	1,710.0	6	886	894	60	120	X	--	--

NOTES: 1/ Client engineers shared engineering responsibility.

2/ Harza services under subcontract to local Colombian firm.

3/ [illegible] Federal Power Commission has been received.

FIG. 1 UNDERGROUND POWER PLANTS ENGINEERED BY HARZA

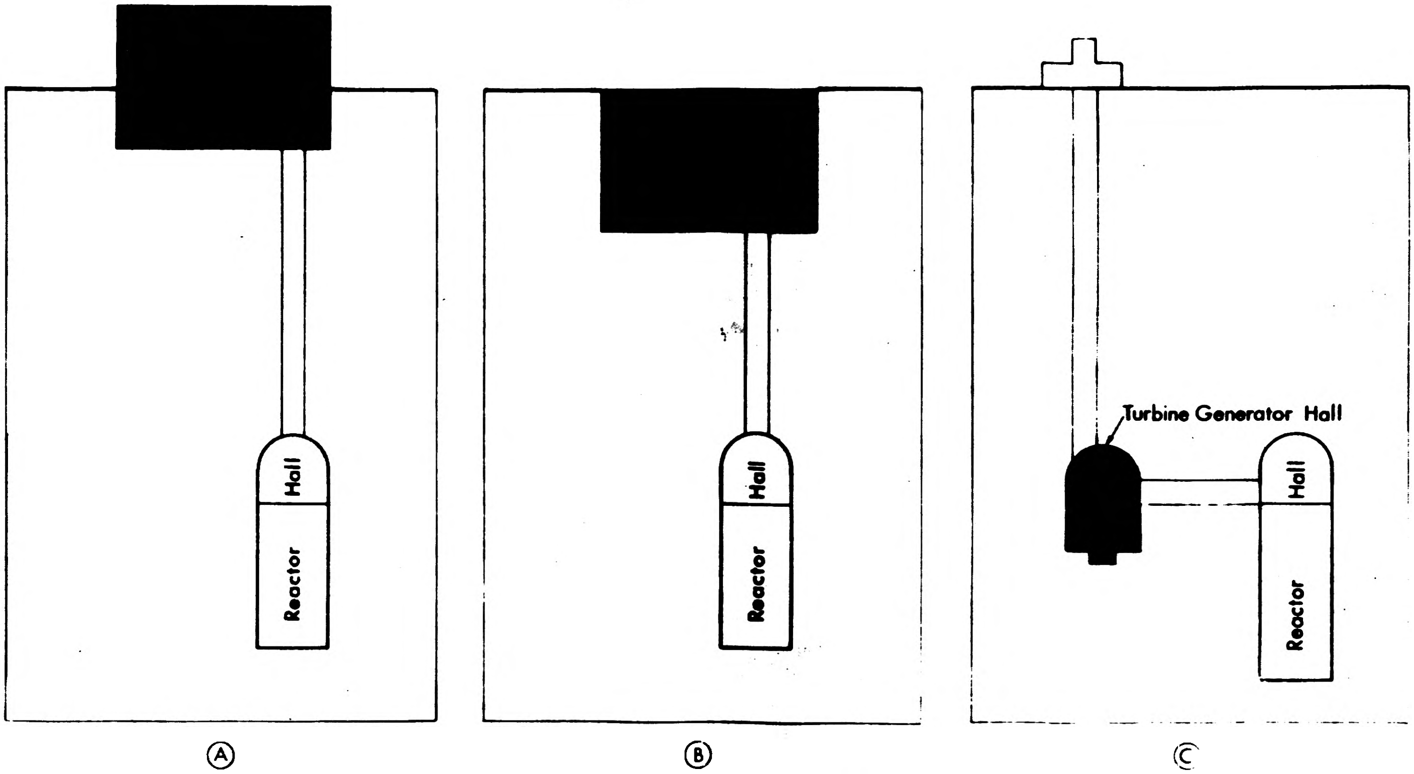

FIG. 2 SCHEMATIC ARRANGEMENT-UNDERGROUND FACILITIES

thereby eliminating the hydrostatic pressures which would resist overpressures in the event of an accident. In such cases, positive protection can be achieved by surrounding the excavated area with a series of wells, which would be recharged to maintain the groundwater level in the vicinity of the reactor and other chambers, thereby assuring the continuing flow of seepage into the chambers (Figure 3). This, in my opinion, answers the concern as to the effect on groundwater expressed by Mr. Golze mentioned in the March, 1973 Professional Engineer 7/.

Chambers and Shafts

The reactor chambers, as studied, that should be adequate for the installation considered are 80 feet wide and 550 feet long. Such widths are practical. The maximum height required from the floor to the roof is 240 feet at both ends of the chamber where the two reactors would be installed. The center section can be stepped up 175 feet in height so that the center or surface area would be 70 feet high. This requires approximately 300,000 to 400,000 cubic feet of excavation. The arrangement of this chamber is shown on Figure 4

Equipment Considerations

The turbine/generator room is shown on Figure 5 and is approximately 260 feet wide, 685 feet long, and 150 feet high, so if this was placed below the surface as proposed for the second arrangement, this involves excavation of approximately one million cubic yards of material.

The shafts required would involve an operational access shaft 25 feet in diameter which would contain the elevator and control wiring. If the turbine/generator facility was placed on

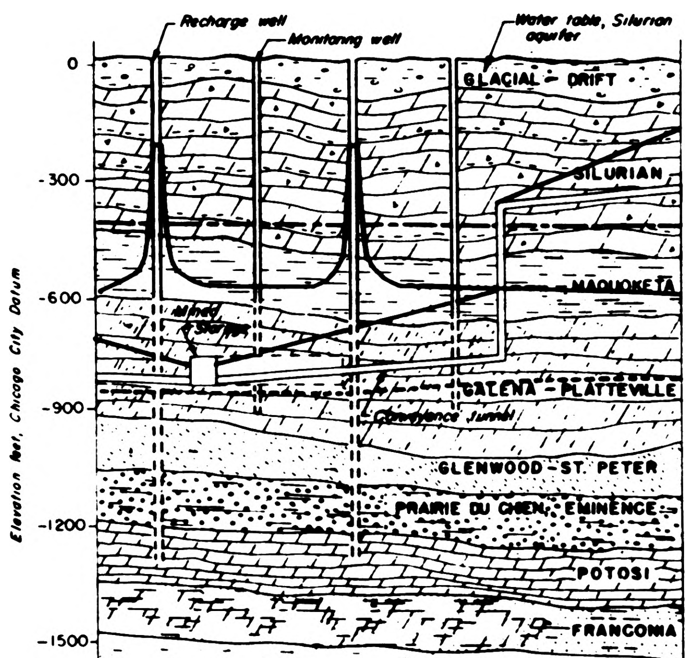

FIG. 3 AQUIFIER PROTECTION

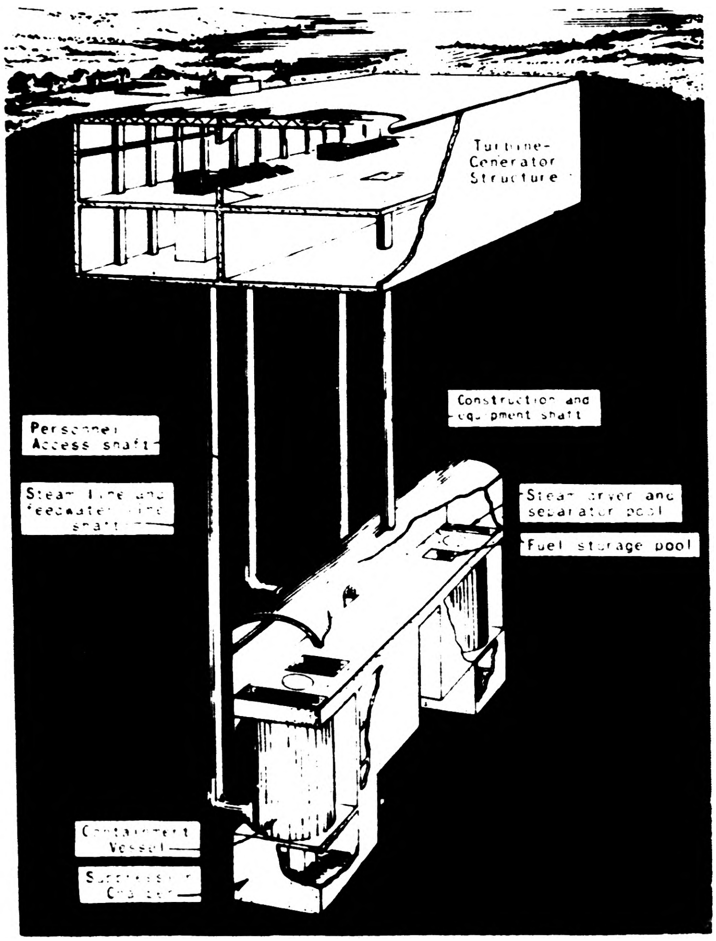

FIG. 4 UNDERGROUND NUCLEAR POWER PLANT

the surface or in a pit below the ground level two additional shafts, 22 feet in diameter, would be required for the steam and feed water lines. The main construction shaft would be about 27 feet in diameter and would be centrally located. These shafts would require a total excavation of approximately 50,000 cubic yards.

The pressure containment for the reactor would be provided by a cylindrical steelplate vessel approximately 100 feet high and supported on an 80 foot diameter concrete cylinder which also serves as the pressure suspension chamber. Biological shielding would be provided by concrete surfaced rock on three sides with a reinforced concrete wall extending across the chamber to form the fourth side.

Some considerations as to other related equipment involve the turbine/generator room, condensers, and transformers. Locating the turbine/generator room at the surface or in a pit means that one of the main considerations are the steam lines. If this is located at the same level as the reactor, this involves other considerations. Assuming that the turbine/generator room (Figure 6) is at the same level, say 600 feet, this would mean that the condenser and associated piping would have to withstand approximately 275 pounds per square inch. In the condensers, this probably would be done by utilizing standard 7/8 inch tubes with .018 inch wall thickness but with stainless steel. This should provide a reasonable safety factor of about 7 or 8 to 1 and with no change in the friction loss. Consideration would be given to going to a heavier wall thickness utilizing admiralty metal which would reduce the efficiency somewhat. Previously, the admiralty metal would be less expensive and the use of stainless steel would be a factor as you need approximately 800,000 square feet of condenser surface for each 1,100 MW unit. However, the copper market today is most unpredictable and so this is included in our contingency estimates.

Locating the turbine/generator at the surface or in a pit involves little or no problems as far as the transformers and generator to transformer connections are concerned. However, if the turbine/generator room facilities are located at the same level as the reactors, a study would have to be made to determine whether or not the transformers should be placed at the surface or in the lower level. Losses of 1,100 MVA transformer would be approximately 5,500 kilowatts and it probably would be best to use water to oil heat exchangers if installed underground. Consideration also should be given to utilizing two half capacity 3-phase transformers as opposed to one single 3 phase 1,100 MVA transformer. Another arrangement would be to utilize six single phase transformers with an additional unit as a spare. The cost of such equipment can change depending on economic conditions but four single phase units should be considered and studied. While the operating record of large three phase transformers is good, the repair of such a large unit, if it was located underground, would present problems, and a spare single unit has some merit.

If the transformers are located underground, it probably would be best to come out with 345 kV SF6 gas insulated bus. If the generator is at the lower reactor level and the transformers are on the surface, the use of solid dielectric cable or isolated phase bus would be a possibility, so as to take the voltage directly from the generator at 20 to 23 kV. This would depend to some extent on the relative cost of aluminum bus vs alumimum or copper cable. There is a pumped storage plant in Japan that went into service in 1970 where the generator leads were brought out by 16.5 kV isolated phase bus 780 feet. This involved 9000 amperes and a 250 MW unit. Another 250 MW unit is to be added. These arrangements and decisions must always be reevaluated and are the function of several factors, including new developments.

Construction Program and Schedule

One of the major problems in our study

was installing the reactor vessel underground, as this was the heaviest and largest lift with the BWR facility. Such a vessel weighs in the order of 900 to 1,000 tons, and while this could be handled, it would be expensive and time consuming to place it underground. Our plan was to fabricate the reactor vessels underground as was done on the Monticello Plant in Minnesota. The procedure in this case

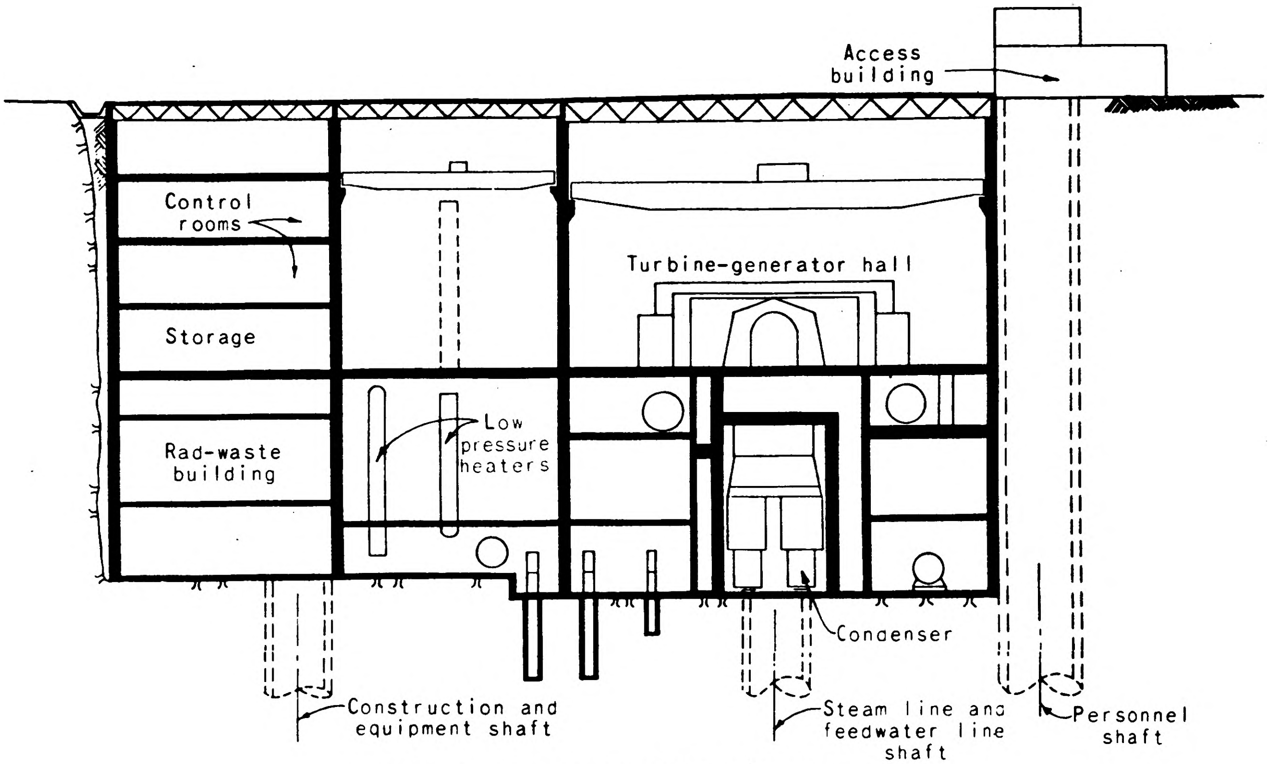

FIG. 5 TURBINE GENERATOR STRUCTURE

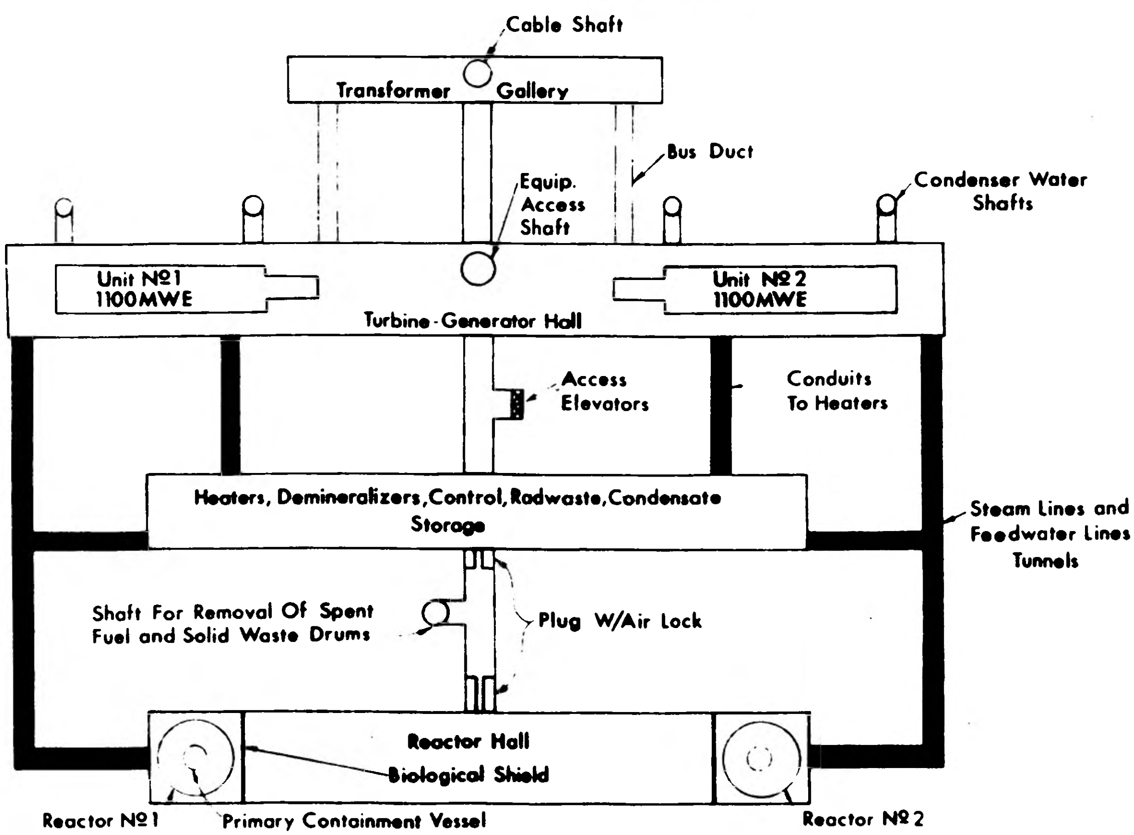

FIG. 6 UNDERGROUND NUCLEAR PLANT

would be to ship the reactor in a number of major pieces with the field welding and stress relieving the vessel done on the site or underground. It is estimated that for a BWR of 1,100 megawatts the heaviest pieces would be approximately 110 tons and 22-1/2 feet in diameter. We have been assured that field fabrication of PWR reactors is also practical and, in fact, there have been several committments for partial field assembly of such vessels, which involves welding steel sections 10-1/2 to 11-1/2 inches thick. The outside diameter of a PWR is less than that of a BWR or on the order of 15 feet.

Other types of reactors would have different requirements and, in the case of the HTGR, the generator stator would probably be the heaviest piece, but all of these can be accommodated with proper planning and preparation.

Figure 7 shows a schedule which is based on what we consider relatively conservative rates of excavation. As shown on the Exhibit, the elevators, cranes, and water control devices would require approximately two years from the start of construction until the underground chamber is ready to receive the reactor. This particular schedule is based on a twenty-five working day month with two shifts per day.

Cost Analysis

The costs considered in this study have been limited to the additional costs involved by placing the nuclear power plant underground. No credit has been taken for reduction of housing requirements which would have to be provided on the surface. The foundation available in such underground stations are superior to those in conventional surface arrangements and no credit has been taken for the simplification in the design and the reduction in size of the foundations that would be required to support the various components on the surface. Layouts 1 thru 3 show the incremental costs of placing two 1,100 megawatt nuclear power plants underground. The quantities of excavation are shown and the actual cost in dollars is shown for the different types of excavation, concrete, and the additional hoists and elevators required.

Excavation of the underground chambers was priced at approximately $27 per cubic yard, including an allowance for protective measures, such as rock bolting and anchors. The excavation of the pit as provided for Layout No. 2 is primarily a quarrying operation and so is estimated at a much lower figure, or $2.20 per cubic yard.

Additional costs are included for concrete, hoists, cranes, shafts and elevators. These are all shown on Layouts Nos. 1 through 3.

Summarizing, the incremental or additional costs for Layout No. 1 is on the order of $26 million to place the two 1,100 Mwe units underground, or approximately $12 per kilowatt. Arrangement of Layout No. 2 would come to $29 million or $13 to $13.50 per kilowatt. Placing all facilities underground as shown on Layout No. 3 would be on the order of $50.5 million or $23 per kilowatt.

As mentioned earlier, no credit has been taken for some savings that would be inherent in the underground installation. If the rock removed could be sold for aggregate, this would reduce the excavation costs. However, it is believed the range

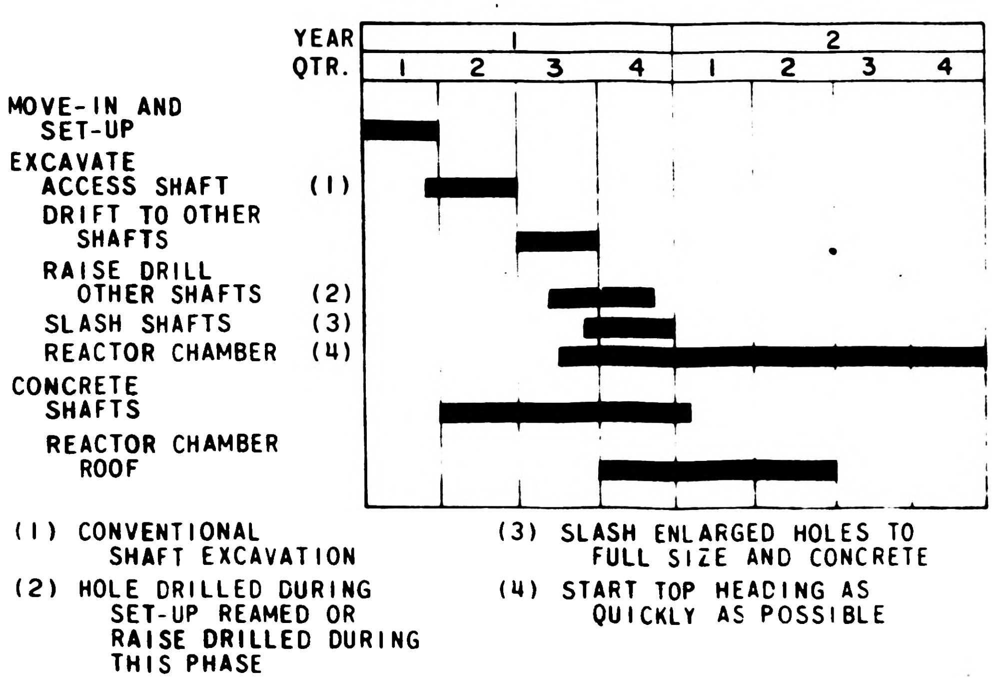

FIG. 7 CONSTRUCTION SCHEDULE

INCREMENTAL COST OF COMPLETE UNDERGROUND SITING
FOR TWO 1,100 MWe UNITS

Layout 1

	Quantity	Cost (In $1,000)
Excavation		
Nuclear Chamber	300,000 cy	$ 8,000
Shafts	40,000 cy	2,200
Water Storage and Passages	10,000 cy	550
Concrete		
Nuclear Chamber Arch	10,000 cy	1,200
Shaft, Water Storage and Passage Lining	17,000 cy	1,800
Additional Hoists, Cranes, and Elevators	L.S.	1,150
Additional Steam and Feedwater Lines	4,500 lf	5,100
Subtotal Direct Cost		$20,000
Contingencies and Engineering		6,000
TOTAL		$26,000

INCREMENTAL COST OF COMPLETE UNDERGROUND SITING
FOR TWO 1,100 MWe UNITS

Layout 2

	Quantity	Cost (In $1,000)
Excavation		
Nuclear Chamber	300,000 cy	$ 8,000
Shafts	40,000 cy	2,200
Water Storage and Passages	10,000 cy	550
Turbine-Generator and Auxiliary Pit	1,000,000 cy	2,200
Concrete		
Nuclear Chamber Arch	10,000 cy	1,200
Shaft, Water Storage and Passage Lining	17,000 cy	1,800
Additional Hoists, Cranes, and Elevators	L.S.	1,150
Additional Steam and Feedwater Lines	4,500 lf	5,100
Subtotal Direct Cost		$22,200
Contingencies and Engineering		6,800
TOTAL		$29,000

INCREMENTAL COST OF COMPLETE UNDERGROUND SITING

FOR TWO 1,000 MWe UNITS

Layout 3

	Quantity	Cost (In $1,000)
Excavation		
Nuclear Chamber	300,000 cy	$ 8,000
Other Chambers	510,000 cy	13,500
Shafts	54,000 cy	3,000
Passages	21,000 cy	1,150
Concrete		
Nuclear Chamber Arch	10,000 cy	1,200
Other Chamber Arches	26,000 cy	3,200
Shaft, Water Storage and Passage Lining	22,000 cy	2,300
Additional Hoists and Elevators	Lump Sum	1,150
Additional Steam and Feedwater Lines	4,800 lf	5,400
Subtotal Direct Cost		$38,900
Contingencies and Engineering		11,600
TOTAL		$50,500

in additional costs involved, depending on the arrangement used, would be $12 to $23 per kilowatt.

CONCLUSION

It is my opinion that it is just a question of time before there are major sized nuclear plants constructed underground in those areas that have suitable rock formations. Psychologically the concern of the public will be satisfied more readily when such installations, that are to be near urban or population centers, will be embedded several hundred feet below the surface in solid rock. The advantages cited in the paper are most significant when such power plants are near load centers.

The geometry and arrangements of the reactors, turbines, generators, etc., studied in this paper are overly conservative, and if we examine the biological needs and the pressure containment requirements, it is logical that it is not necessary to provide the same degree of protection in chambers below 400 feet of rock that is required on the surface. This would allow a reduction in the cost. However, the incremental or additional costs of $12 to $23 a kilowatt, depending on the arrangement, compares quite favorably to other extras or additional expenses that have been accepted to meet environmental needs.

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III - SOLAR AND WIND ENERGY

CO-CHAIRMEN:
DANIEL K. AI AND JACK L. BOONE

INTRODUCTION

Dr. Jack L. Boone

In recent years the scientific community has begun to explore the many alternatives of using solar energy in terms of solar energy conversion schemes. These, in general, may be classified according to use. We can talk about solar to low-grade thermo residential heating and cooling applications. We can talk about solar to high-grade heat for such applications as steam powered generation and certain high-temperature conversion processes. We can talk about solar to electrical for either residential or for large power production installations; and we can talk about wind to electrical and this would, of course, come in both large and small packages. We can talk about wind to mechanical in terms of storage schemes or for direct use in mechanical energy. Along with these basic conversion processes comes a whole myriad of problems of processing, storage and utilization of energy in its many forms, and perhaps the biggest problem associated with the utilization of solar and wind energy comes in an indecision which comes from results from having too many alternatives. The scientist today is confronted with the task of performing a preliminary cost and value analysis in an effort to justify any system that he introduces, and to me this seems to decribe the current status of many of the solar energy schemes that we are considering. It is hoped that the speakers here today can place some of the solar energy conversion schemes into proper perspective, not only in relation to other energy resources, but in relation to one another.

PROSPECTS FOR CONVERSION OF SOLAR ENERGY INTO ELECTRICAL POWER

William R. Cherry

NASA

Goddard Space Flight Center

In 1972, the Solar Energy Panel took a broad look at solar energy across the whole field to see just what could be done with this energy source. Maybe the era of acquiring energy without regard to cost and without regard to consequences of using it is beginning to come to a close and maybe we ought to start looking at the newer sources of energy, even though we need every bit of energy we can get from every source. I am not trying to say we don't need gas, oil, coal and nuclear energy. We are not going to use solar energy at the North Pole in the middle of winter and we are probably not going to use fossil fuel energy in places where we can get a reasonable return on solar energy.

The Solar Energy Panel labored hard and really got this field in good perspective and I would like very much to show you what we came up with in that labor. First of all, we identify three areas where we thought that solar energy could have a major impact on future needs. First, thermal energy for buildings, that is the heating and cooling of hot water associated with dwellings, as well as commercial buildings. Due to the fact that there has been a great deal of work done in laboratories at most universities, we felt that this could be brought into commercial readiness (commercial readiness means that we could begin mass producing commercial heating units within five years). Clearly, it appears to be still further away and will take some more development to bring it about, so we estimate by the latter part of the 1970's we will have good systems that will combine both heating and cooling.

Another area that looked very attractive was the production of renewable clean fuels, such as gas. Kansas City, I understand, derives a good deal of their energy from just this very same. We can get hydrocarbons and we can get solid fuels and carbon fuel by charr, that results when we go to a destructive distillation process, and your paralysis process results in the production of oil from organic materials.

Now, if the farmers can take up 15% of our land to make our food, which is 1% of our energy, why can't we devote a couple percent of our land for making energy or making fuel? And we feel that this can be done--the big thing is ENGINEERING--how do you harvest the crops and provide this fuel at the right time and right places in order to produce your energy? Our estimates were that in about 5 to 8 years some of these processes would, indeed, come about and very happily we are seeing some of the cities starting to begin to recycle some of their garbage and that is a big step in the right direction.

For the third area we felt that solar energy could have some impact in the electric power generation area; by concentrating the energy to get high temperatures, which in turn boils water to produce steam, or through solar cells such as those used in the space program since 1958, which can convert sunlight directly to electricity. Wind energy is another one, as well as ocean ΔT which has to do with the production of electrical power when energy is derived from regions where you have the warm overcurrent or very cold undercurrent. On these I envision that it is going to take some development and maybe even a little research to get the costs down to where we can really look good in various areas.

Let's take a look at the availability of solar energy and this has to do with the electric power we think we are going to be consuming in the United States over the next fifty years, from about 1970 up to 2020. In 1970, we consumed something like 14×10^{15} BTU's just to generate our electricity. If our projections are any where near accurate, we see that this is going to increase. Let's pick on the current century somewhere around 76×10^{15} BTU's will be used to generate the electricity we'll use in the United States by the turn of the century. Now, why if we are not going to have that many more people, is that going to happen? Well, we seem to be going more and more electrical - we like the convenience of it even though it is quite wasteful and it appears that today we are using somwhere around 25% of our total energy to make electricity and by the turn of the century the numbers that we have is somewhere around 45%. It does appear that we are going to be using more and more of our total energy resources for producing electrical power and how in the world are we going to get it? Well, we are going to get it from gas and oil and some of these are going to become synthetic gas and oil, manufactured from coal or shale or tar sands, and we are going to find a good deal more of the natural material in the ground.

Solar energy arrives in the United States at the average rate of about 1500 BTU's per square feet per day; if we could convert that at 10% efficiency, we need about 1 1/2 to 1 3/4 percent of the United States to generate the equivalent of all the energy we need to produce our electric power. Well, if we look at the production of electricity from solar energy by the various processes that are available to us, we come up with some very interesting things. First off, we can have what we call 'kind of a natural collection of solar energy' - that would be by wind power. We estimated that somewhere around 50 megawatts per sq. mile could be generated from wind energy. Now, there are about five regions in the United States where the wind blows steadily enough and high enough velocity where wind power could be attracted. Along the Eastern seaboard, particularly in New England, through the prairie here and the Great Plains of the United States, around the Great Lakes, of course, down the Rockies, along the Cascades along the West Coast and on the Aleutian Islands there is a great deal of wind.

Another renewable energy source has to do with the particular case of growing fuel and burning the wood. We get somewhere around 2 to 3 megawatts per square mile because photosynthesis is not a very efficient process, as a matter of fact, somewhere around 1%, although some of the agricultural people associated with the panel thought that this could be increased, perhaps to 2-3%, making it far more attractive. Ocean temperature differences again is the use of warm overcurrent with some very low, or cold, undercurrents and using a heat engine to extract that energy, operating a Turbine for generating electric power, and there is a lot of energy - 400 megawatts per square mile. Then if we go to a more technological type of collection scheme, we come into thermo energy where we are using concentrators and the thing here is that you must use these in regions where you get a high percentage of direct sunlight. So in regions where it is suitable, say in the southwestern United States, assuming about a 20% efficiency system, you can get something on the order of 100 megawatts per square mile, so you need about 10 square miles for a thousand megawatt power generating plant.

George Sagel made a study on the production of wood to operate a power plant that he defines is a thousand megawatt steam power plant - with 35% efficiency and 75% load factor. He says solar energy is converted by plants somewhere between 24 and 1%. Again, plantologists say it is an insult if you can't grow stuff with 1% efficiency on the land. In a typical growth region we see that we need somewhere on the order of 400 sq. miles to provide fuel on a continuous basis - night and day - 365 days per year, to keep that plant on the line. What this amounts to us is that after a 20 mile by 20 mile sector is planted in trees, they will then begin to harvest regions of this plot until you finally wind up making a complete cycle in a period of about 8 years. This will provide sufficient width to operate the power plant.

We found that in the four corners area they are able to collect solar energy and convert it at 10% efficiency we'll actually have more energy produced from the sun that comes in there every year than all the energy they got from coal they have dug out of there so far. The fact that they only receive the energy from the coal once but the energy from the sun is there every year is the important item. Let's take a look at the four corners region, where we might use solar concentrators and where we have a possibility of collecting the solar energy at high intensity. This energy is piped to the power plant and water is used to generate steam in a conventional way. The big problem here is that you have got to have a region where there is a good deal of sunshine. But, if such systems can be made economically, we can generate some large amounts of power, particularly in the southern part of the United States.

We have, as I mentioned, done some work on solar cells for a good many years in space problems. We are actually finding now that there are many ground applications for solar cells, particularly in unattended and remote locations; where we want to operate navigation aids, warning signals, remote communication systems. We are actually beginning to find that these systems are very competitive; actually less expensive to put on the line and to maintain than the conventional butane-propane burner-type systems that have been used for many years, particularly in navigation of the ocean. Right now , the cost of these things are on the order of about $50 a watt. They can envision that if there is a large enough business, just making them the way we are now, that these costs can actually be brought down to somewhere near $20 a watt. If we can get some automation, we can envision that it will get to $10 a watt and then to get down to $1 per watt is going to be one of the major developments that will have to take place. That is why we are putting 10 to 15 years as the time element required in order to get these costs competitive to another method. You probably are familiar with the Delaware House - it is an experiment to show that we may be able to get a reasonable amount of our electric power for the house from a collector. Now this collector is designed to intercept the solar energy, to generate electric power, the thermal energy to heat is absorbed and is picked up by the air and stored in the basement. They are getting now some of their heating, cooling, hot water and electric power to operate the house. They hope to get about 70% of the total energy of that house derived from the collectors, both the thermal for heating and cooling as well as the electricity.

What sort of thing has to be done before we are going to break that $10 per watt proposition and get down to something under $1 per watt? Necessary for making this panel that costs something under $1 per square, is the solar technology that has got to be brought to bear before we are going to see the widespread application of solar cells on the ground. It seems to me that these proximities can be automated and put to the point where the labor costs are very minimal and amterials themselves can be very simple and very much available, and we can get low-cost solar rays which can be used in many, many applications throughout the country. Not too long ago, about three years ago, we were up against the problem of trying to get high quality reflective coatings on the glass for buildings. One of the organizations that was heavily involved in making coatings for spacecraft solar rays, found that they could build a machine that was capable of taking sheets of glass 2x4 feet and automatically introducing these into the vacuum, putting on the deposit and collecting these at the end of the machine with about three people operating the whole process. The costs on coatings dropped 2 orders of magnitude when they got this machine in operation. Just to show you what can be done when you get away from batch and hand operations rather remarkable things can take place. I guess that this is what is going to happen in the solar arrays. To lay a wquare mile of array which would give us then 10 megawatts of electric-generated capacity--this is the thing that I have been saying is some years off before we are really going to see that. We might take another step and go up above the weather and see what we can do at that point. I had an opportunity to take a look at the possibility of floating a mattress above the weather, just to see what I could come up with. First, I wanted to know where the jet streams were, cause that is a nice thing to stay out of. If you can get up somewhere around 1700 feet, or more, you can get pretty well out of the atmospheric disturbances, get over the thunderstorms, get out of the main jet streams and you can maintain a system at that point. This is only a tenth of the atmosphere. If you can build a structure which is about a hundred feet thick and a mile square, you would have a generating capacity of 250,000 kilowatts. A quarter of a million kilowatts of generated capacity. Of course, you would have this thing with the sun shining on it, you'd want to collect your energy in different places, and then you've got to somehow get that power from the mattress back down to the ground. There are a couple of things you might do, you might put it on a teather, or you could microwave this energy to the ground.

I guess you've all seen a photograph of our sky lab, which was a very successful operation. They managed to rip off one panel during launch and in spite of that, the mission was a tremendous success and did manage to provide those people with the electric power that they needed during the year. Peter Glenjours talks of a satellite solar power station. You plant this at a synchronous altitude and at that point you have mostly sunlight hours, as a matter of fact, you only have a 70 minute maximum interruption during equinoxes about 42 days one side and 42 days on the other side, in the spring and fall. This otherwise is totally in the sunlight. He has looked at the possibility of something under the order of 50 square kilometers, 25 square kilometers in each collector, bringing the power to a transmitter which converst dc into microwaves at about 3 megahertz. Beam this to the ground, where, of course, it is reconverted back to usable electric power. There are at least four major problems associated with this, we aren't even talking about money right now, but let's talk about the four major technical problems associate with the idea. First of all, there is the problem of geeting very low cost solar arrays. These things actually have to come to something of the order of 10¢ to 20¢ a peak watt, in order to come anywhere close to being economic for such a system. The other thing is, getting this into space. This weighs about 50,000,000 pounds, a station of that magnitude would require, with the rockets being developed today, about 3,000 launches. In other words, we have to have a better system developed for getting materials into space. Anther thing, of course, is deploying, orienting, station keeping and attitude controlling all the system. This is several million times larger than skylab which, of course, is the largest thing we have put up so far. The problems associated with that are enormous, but NASA is always willing to face a challenge and this would be a great challenge. The last area, the fourth area, that needs to have considerable investigation and development done, is conversion to microwaves and beaming these back to the ground. There are a lot of arguments as to whether or not this would cause some sort of a physical problem with people getting bathed in microwaves. The answer is 'no', we aren't talking about an intensity anywhere near that. The density is something around 20 milliwatts per square centimeter. Sunlight comes to the earth's surface on a very bright day somewhere around 100 milliwatts per square centimeter. We just aren't going to have any ill affects from that sort of thing. We are always worried, of course about costs. On this I divided it into two parts; the real world and the imaginary world. We don't have any doubts at all that installation costs, at least in 1972, for gas, oil, coal, nuclear, that is, light water reactor plants, were in a range somewhere from $250 all the way up to pushing $500 per kilowatt capacity reactors for installed fuel for nuclear plants. The people working on fast breeder reactors really don't know what those costs are going to be, some are as low as $500 and some are even over $1000 installed kilowatt. As you get into solar thermal systems, there is a very wide estimate here as to those costs ranging from the super optimist of $300 an installed kilowatt to over $2000 an installed kilowatt. It's probable, if you have to make an educated guess, it is more like $1000 an installed kilowatt. If you wanted to build space systems right now, it would cost $200,000 a kilowatt, you're not going to have many stations that cost like that. They've got to come down in cost before we can really talk about competition. The Ocean ΔT System is in need of engineering, of course, ship building and heat exchangers, and we know quite a bit about ship building and heat exchangers, the question is, can you build them big enough, can they work efficiently enough in that system? Those costs look like they might be very competitive with conventional systems, as we know it today.

Wind generators look like they could be very competitive in the systems coming down the line, and we feel that in the woodburning, the only new thing here is how to construct a large plant and get it ready for combustion. The power plant is going to be just like any conventional steam power plant, just a matter of burning the different kind of fuel.

We are always interested in what is happening on the finances; there was very little money that actually went into solar energy in 1971. Something on the order of $90,000 for terrestrial I'm talking about not space. In 1972, somewhere around a million, 1973-2.6 million, 1974-6.5 million went into this whole thing and then in 1975, a couple of weeks ago, it was 17.3 million. This is a very hot topic now and we are not putting enough money into solar energy development. It turns out that instead of the recommendation made by the AEC for 32.5 million, the Office of Management and Budget said that figure should be nearer 50 million. So the field is beginning to increase, we are beginning to see more dollars coming into it. I'm sure that we are going to get many new and good ideas are going to start to break this field wide open where we are going to have a chance for solar energy to become more prominant and, here comes another one, find it's place in the sun.

THE U. S. WIND POWER PROGRAM

Joseph M. Savino

NASA

Lewis Research Center

Today I would like to talk about wind energy in, basically, two parts. I would like to bring to your attention some of the developments that have occurred in the 20th century. Many of us who have gone through school in the last 25 - 30 years don't recall anywhere in our engineering education much information dealing with wind energy, and that may come as a surprise to you as it did to me, to learn how much has actually been done in the 20th century to develop large scale wind-driven machines. After I get through with that introduction I would like to briefly outline the program that the National Science Foundation and the Lewis Research Center have put together for the next five years.

Why are we interested in the wind? In the future our energy demands are going to be of such a magnitude, there is no way that we will be able to meet those demands using conventional methods such as oil, coal and nuclear. Our fossil fuels are too valuable for other purposes. So, it appears to many of us that the future is probably going to be requiring a mix of energy systems. In other words, any method that promises to produce a significant amount of energy ought to be at least examined and developed to the point where we can honestly say we know what the energy will cost us. Modern-day wind systems have been worked on since around the turn of the century. As you examine some of the literature, which is incidentally quite hard to get, one thing comes through loud and clear. That is, although there have been a number of individual efforts to develop big systems, no one of these efforts was sustained sufficiently long enough to carry the program to the point where you could build reliable systems that would function unattended for a long period of time. None of these efforts ever carried the technology to the point where you could honestly say you knew what the costs of these systems would be. The wind-driven machine dates back, recorded history in western Europe to around 1100. As the centuries passed, the technology only improved as rapidly as new technology became available. As a result, you will see photographs or sketches of old windmills which were put up facing the prevailing winds, when the wind changed direction, then the mill didn't operate. Somebody got the bright idea of rotating the rotor into the wind whenever the change in the wind occurred. As time went on, these improvements came along very slowly. It wasn't until the latter part of the last century that some rapid strides were made and this was chiefly due to the appearance on the scene of some new technologies, namely, the technology provided by the field of aerodynamics, electrical power generation and, of course, we acquired a better understanding of how to design structures efficiently and less expensively.

I would like to point out to you some of the large machines that have been built and what happened to them since around the turn of the century. It might be of interest to you to know that around 1908, in Denmark, which is a rather small country and has almost no fossil fuel resources of its own, and had 33,000 wind-driven machines on its land. Some of these were used to generate electrical power, some to grind grain, to saw wood, and also to pump water. It had been estimated that these machines, if you totaled up their maximum capacity, it would be equivalent to approximately 200 megawatts of electric power. That is how much power could be derived in Denmark in 1908. That is a rather formidable number for that period of time in such a small country.

Most of the developments in wind energy machines have occurred in western Europe and in the United States and some in Russia. The first large wind machine built in the world, at least, as near as I can tell from the literature, was built in Russia in 1931. The tower is 100 feet tall, the rotor is a two-bladed propellor measuring 110 feet from tip to tip, and it produced a maximum of 100 kilowatts of power in wind of approximately 30 miles an hour, or higher. If you look carefully at this machine you will find all of the machinery in this case is located in the top of the tower and this inclined strut rests on a carriage, as a circular railroad track. Instead of the attendant going down and walking that around, it was automated, whenever the wind changed directions that little carriage would move the strut around so that the rotor faced the wind. This machine operated for a period of ten years and it was destroyed in World War II. In that time, apparently it operated fairly successfully and it provided electrical power into the Russian network. What has been going on in Russia is a little bit of a mystery though I do have some knowledge that I have acquired recently. Russians had intentions of building very large machines, but they never got around to it, instead they spent a lot of effort developing smaller machines for use in isolated villages and towns around Russia.

A wind-driven turbine was built in England in 1950. The tower is 80 feet tall, the rotor measures 80 feet. This machine has a different mode of operation. The tower and the blades are hollow. The wind blows from left to right. In other words, the rotor is downwind from the tower and the rotating rotor acts as a centrifugal air pump. So, air is sucked into the tower at the base, travels up the tower and out the rotor tips. In the base of this machine is an air turbine which spins as the air goes by and that air turbine drives an electrical generator. This particular machine was moved to Algeria, where it operated for a while, but again the literature gets sketchy on this point. I have no idea whether this machine still exists or how well it operated, because for some reason, people in the wind business didn't do a very good job of documenting their results. So, the results we have not been able to copy from a lot of the technology that was developed in the past. The British were extremely accurate in the wind business through the 50's. Nothing new had been done since about '61.

The Danish constructed a large mill on one of their islands. The rotor sweeps out to an area 80 feet in diameter and it produced 200 kilowatts of power in wind about 33 miles an hour. Built in 1957, it ran successfully until 1966 at which time it was dismantled. It was just yesterday that I got a report on this machine and haven't had a chance to read, but I think I saw some figures that indicated that this machine would have been cost effective at that time, if the fuel costs twice what it did. If the fuel prices would have gone up by a factor of 2, at that time, this machine would have been producing power in competition with fossil fuel plants. In World War II, in Denmark, some of its power was provided by wind-driven machine, and in some instances, those wind-driven machines did produce power which was cheaper than could be gotten from fossil fuel plants. That is the last big machine that was built in Denmark and since then nothing more has been happening.

I'm going to show a movie of the Smith Putman Machine in operation, in a short time. The technical success of the Smith Putman Machine prompted the Federal Power Commission in 1945 to take a serious look at wind power as a possible source of energy. A man by the name of Percy Thomas led a team of engineers and they took a look at this problem and came up with some conceptual design to wind turbines. This is one such concept. The height of this machine was to be 475 feet, each of these rotors were to be sweeping an area of approximately 200 feet in diameter, and this was rated to produce 6.5 megawatts of electrical energy in winds 28 miles an hour or higher. A sister machine to this was to produce 7.5 megawatts of power. In 1951 they went to Congress to try and get some money to build a prototype, they weren't successful because the Korean War had broke out and at that time too much money was going into the war and there wasn't enough money left over for such projects such as this. As a result, the demise of this attempt was also the demise of the effort in the United States. Since that time, nobody that I know of has seriously suggested that we go after wind as a source of energy until the last few years.

Basically, the point of this discussion is that large wind-driven machines have been built in the past, there is no problem with building them. We can do that. The problem will be can we build them so that they will be reliable, will have a long service life, say 20 years or more, and will they be able to give us energy reliably at a cost we can afford to pay?

We are now taking a serious look at the wind power and we hope that the NSF-NASA wind energy program will provide the sustained effort to develop these systems, so that they will produce power at a price people are willing to pay. An objective of the five-year program is that we want to develop the technology, so that wind power systems can supply energy reliably, and at competitive costs. Also want to be sure that if we are successful in the objective, that the second will also be achieved. Namely, we want to be sure that the appropriate users will be anxious to use them. In other words, it is very possible to go out and build a system which is terribly successful, but then nobody wants it. How are we going to do this? First of all, we are going to have a government planned and managed program. The NSF is the lead agency and the NASA Lewis Research Center is playing a major role in developing the technology. We are going to have in-house efforts and we are going to do a considerable amount of our efforts on contractual basis. To help implement these systems and to be sure that they will be accepted by the ultimate users, very early in the program we are going to solicit participation by the ultimate user and by the people who are going to supply the components, eventually. We are going to do this, hopefully, the users by being involved. We are thinking of the utilities in this case who have the engineering experience that goes with building and testing these systems, and we also have appeal for the operating and also their initial capital costs.

Out of the NSF will come mission analysis studies. They will support much of the work that will go into sensing what the wind energy resource of the country is, and to try and develop that wind energy resource even further. At our Center, we will be responsible for many of the conceptual design studies, parametric studies, preliminary and final designs of actual hardware. On contracts we will probably do all the fabrication and assembly of the system, and also in cooperation with the users, we will do fuel testing of the system in actual real-live applications. Our in-house efforts will be expanded; we have a project office, that is a group of men who have been assigned to work only on wind energy. We are going to design, test, and do research on an experimental machine. We are also going to do the planning in cooperation with NSF and the management of contract efforts and we are going to maintain very close liaison with the utilities and ultimate users and the suppliers' components. Let me address the mission analysis study. If you were doing this program in sequence, you would probably do this kind of a program, before you did anything else. You are running a little bit of a risk by doing something in parallel. We are developing the technology, assuming that the mission analysis is going to back us up. We are interested in identifying what the suitable application will be for wind energy systems. We want to know how much power will be needed in areas where it is suitable. What form should the energy be? What are the interface requirements? How do we connect a wind driven system with existing application? How is energy being used in these different applications - on a daily basis, weekly basis, monthly basis, a yearly basis? What will be the energy storage requirements? What are the wind patterns in a region where the applications exist? A cost benefit analysis had to be done. Are the benefits going to be worth the cost? Also, we are going to be concerned with environmental impact. This particular study is going to be started probably in July or August of this year.

How much wind energy is available in the country? Some people have taken a cut at this and have estimated that there is enough energy in the country to produce a significant amount of electrical power. By significant we mean, anything larger than a few percent. In this part of the program we are going to want to make an estimate of how much wind energy is available, we want to identify the windy regions of the country, we want to make additional measurements in areas where no measurements have been made, we want to take a look at the existing wind data which is usually recorded at places like airports, which are not noted for their windy atmosphere, and we want to see whether that data can be used in a matter suitable for one system, so we want to apply a direction factor, if necessary, to existing data. We want to develop the prospecting tools that are needed to find where the winds are. So that means we will probably study the interaction between the wind and the terrain, do an analysis by wind tunnel testing, field testing, and hopefully we can even use the earth's satellite to help us find wind placements. This analysis program is going to start early next year.

One part of the program is already underway, we call it the wind damaging convergence system or what you saw here on the slide. It is the machine that interacts with the wind to extract the energy. We don't know what size machine is going to give us electrical energy, or say energy at the lowest cost, nor do we know its configuration. Will it be one large rotor to a tower or will it be a bunch of little ones on a single structure? So, the objective of this part of the program will be to identify cost effective configurations and we want to develop the technology that is going to be needed to produce the cost effective reliable systems. The approach is essentially the same as before. We are going to do in-house and contractual effort, we'll strive to support conceptual design parametric study and preliminary problem design. We will bench test a lot of components and subsystems in the laboratory before we put them up on the tower. We will actually field test complete systems in cooperation with the user, in their applications. This program plan has already been worked out and the execution of it is in progress right now. At the present time we are designing a 100 kilowatt experimental wind generator system, which we call our Model 0 Machine. The main reason we are building this machine is we want to acquire some engineering data and experience of our own. There is a lot of technology that can be brought to bear in this particular area. The problem is that nobody in our organization has any experience with wind-driven machines. The best way to do this is to go out and build one and run it. After we do that we hope that this machine will be used as a test facility in which we will field test new and improved components.

I'd like to show you a sketch of this machine. The tower is to be 100 feet tall, this rotor will sweep out an area 125 feet in diameter, and the wind blows from left to right. It is designed to run both synchronously and asynchronously about 1800 rpm, 440 volts. It will start producing power in 7 miles an hour wind and produce maximum power at 18 miles an hour, or higher, and we plan to shut it down in 60 miles an hour winds. Right now the preliminary design on this machine is about 35 percent complete. As an additional part of this program, we have the following plan: Medium-sized machines from 50 - 500 kilowatts, we expect the Model 0 to be in operation July 1975. The Model 1 which will be built on contract, we hope to have about five of these in operation in actual application by October, 1976. A Model 2 by January, 1979. We hope that by early 1980 we will have a multi-unit 10 megawatt system in operation. We have lots of ideas on energy storage. I thought I would read one to you that you would find interesting or amusing. This letter came from Dayton, Ohio.

'Perhaps I have the answer to provide a 20-mile an hour wind speed at all times without depending on the wind alone. This is my suggestion. It can be used anywhere in the U. S. You provide yourself with a motor driven fan large enough to produce a 20-mile an hour wind and place your windmill in front of it to produce electricity and sufficient power.'

In this country we are used to having power available on demand, when we want it. So the objective of this energy storage program will be to develop an energy storage system which, when coupled with wind power systems, will make the wind system a firm power source. We are just getting started on this program. There are many ways to go on this and since we are just starting, we have to assess which of the various methods are suitable and then we are going to have to get into the actual work on developing this system so as to reduce the cost of the systems and we are going to do this with some in-house and contractual effort. Hopefully, the systems for which the technology already exists, we can design some experimental units that we will test with our Model 0 system.

We also plan to have a subprogram which we call Informative Research and Technology. The purpose of this program is to acquire the technical data and experience that we need to conduct the program. You can't conduct a program if you don't know what you are doing. We hope to acquire that know-how through this program.

Also we are interested in improving the performance, the service line, and reducing the cost and lowering the maintenance of the systems. We also hope to support the research and development of new ideas that come along such as the vertical axis machines. We will be doing again in-house contract work. We will do all kinds of analytical and experimental investigation, laboratory bench tests, small scale testing, fuel testing, etc. That program is, in part, underway at the present time. Here are some sample projects that we are going to look at. No one in the country knows how to build wind driven rotors that are low cost and long service life. Helicopter rotors are expensive. We would like to have electrical generators that are better suited to being driven by the wind. We want to look at vertical axis rotors. We want to examine the problem of putting more than one rotor on a single tower, we need to know something about the optimum spacing between towers, and we want to know what the cost optimum number is per tower. We want to know something about the tower and rotor interactions. In this particular area a lot of the work that has been done in the past has not been properly documented so we are going to have to relearn this all over again. We can't take advantage of previous work on this, because it is not readily available.

In 1973 the National Science Foundation spent about $200,000 on wind energy. This year they will be spending somewhere between 1 and 1.5 million. It has been estimated that in 1975, this could go up to as high as 7.5 million. In Dixie Lee Ray's report to the President, December, 1973, the Wind Energy Program for five years totaled $30 million. Of course, they should put a disclaimer here. Anything I say here should not be held against me. These are our plans. They are subject to change, simply because we don't know how much money is going to be available from year to year. Also, the climate in the land has an awful lot to do with it.

In summary, I would like to say that the wind has several advantages. It is an inexaustible source, it is nonpolluting, in the sense that there are no waste products to get rid of, and it has also served mankind quite faithfully over the century. Wind-driven machines are technically feasible. We can build the machines. The problem is that they are not economically feasible. That is really where the problem is. NASA-NSF Wind Energy Program is aimed at making wind-driven systems reliable, and we want the energy to be available on demand and we want it to be available at a cost which is competitive with other systems.

SOLAR-THERMAL ENERGY CONVERSION

By

Dr. E. R. G. Eckert
University of Minnesota

ABSTRACT

The fact that our conventional fuel resources are finite and will be exhausted some time in the future gives impetus to a consideration of solar radiation for conversion into heat or electric power. The characteristics of the solar radiation - that the enrgy flux density is small and that it arrives intermittently on the ground of our glove has to be considered in any system utilizing this energy source. For home heating parts of the roof offer a sufficiently large area, for electric power production areas of some km^2 are required to collect a sufficient amount of energy. Optical concentration, thermal collection by a fluid and electric collection are generally used in series. A crucial element in any scheme is the design of the solar collector. The conditions imposed by the specific application and the possibilities to obtain high collection efficiencies are investigated. Recent developments in thin film technology have provided means for improvement of the absorber and the glass envelope of the collector, and have brought solar thermal plants closer to a condition where it is competitive with other energy sources.

A SOLAR-HYDROGEN ENERGY CONVERSION SCHEME FOR AGRICULTURAL USE

R. L. Reisbig, J. L. Boone, G. E. Weiss, T. Van Doren

Engineering Research Laboratory
University of Missouri-Rolla
Rolla, Missouri 65401

ABSTRACT

A solar energy activated system is presented which can produce hydrogen and hydrogen-derived fuels (methanol) for use on farms. The device, named "solar-kine", also can produce fertilizer (anhydrous ammonia) as a byproduct of the hydrogen. A cost analysis shows that solar-kine may be mass-producable and sold to farmers for between $7,200 and $14,700. This is equivalent to giving the farmer energy at a price of $1.79 to $3.66 per million BTU's (in 1974 dollars). Presently (Spring, 1974) regular gasoline used in tractors at 43¢ per gallon, represents a cost to the farmer of $3.77 per million BTU's. As oil-based fuels increase in price in the next few years, solar-kine may represent a reasonable alternative to keep food prices down.

The solar-kine system uses concentrated solar energy which can be converted into a high-density electric current by means of a thermionic heat engine. The rejected heat and electric current from the thermionic converter is supplied to an electrolysis cell which, in turn, produces hydrogen and oxygen gas. Chemical process equipment will use the hydrogen and oxygen to produce a methanol (CH_3OH) fuel supply for internal combustion engines used on farm machines. The hydrogen can also be used to manufacture ammonia, ammonium nitrate (NH_4NO_3), and ammonium sulfate [$(NH_4)_2SO_4$)] fertilizers. The following materials can be produced which are useful to the farmer: a) hydrogen gas, b) oxygen gas, c) liquid tractor fuel, d) fertilizer, e) ammonia, f) electricity, and e) heat energy.

We feel that any unconventional energy system, such as solar-kine, must interface and serve the conventional use of fuel energy if it is to have lasting merits. This is why we feel that it is desirable to have the complete conversion of solar energy into a liquid fuel that is safe to handle and store, and which also can be used in any conventional fossil-fuel burning system with minimum modifications.

Solar energy is compatible with our environment; it is free, and its supply cannot be exhausted. It is also available at any geographic location without requiring transportation to the user's site (See Fig. 2). Its major advantage over fossil fuel comes from the fact that it does not add any net heat content to the earth [5,6].

A small on-site energy system is best for the farmer because,

a) It can be mass produced at 10^6 or more, units per year,
b) Power levels needed by farms are low, 100-500 KW,
c) Farm energy is used over a large geographical area,
d) The main source of energy (the sun) is everywhere available,
e) Heat rejected from the heat engine (thermionic) is used in other portions of the system to increase overall efficiency, and may be used in part to heat buildings,
f) The farmer would be energy-independent from the price and supply undulations of the industrial complex,
g) Legal considerations which regulate the large energy distribution systems would not apply, or affect, the proposed system as used by the farmer,
h) Last, and possibly most important, the farmer would have a dependable fuel supply at the lowest possible cost. In the future, the proposed system will supply energy at a cost much lower than petroleum-derived energy.

THE SOLAR-HYDROGEN AGRICULTURAL ENERGY SYSTEM

Figure 3 shows a schematic diagram of the major subsystems in solar-kine that will be required to make solar energy available to the farmer.

The subsystems are discussed in the order that the energy flows through the system solar collectors, thermionic heat engine, hydrogen electrolysis cell, and chemical processing equipment.

Solar Collectors and Heat Transfer Equipment

The solar collector and concentrator subsystem is a major cost item in Solar-Kine. The 100 KW unit will require 171 to 200 square meters of collection area, depending on the collection efficiency one may expect. These numbers are based on an assumed collection time of 1200 hours per year (200 days at 6 hours per day). Missouri receives an average of 2,000 sun-hours per year.

Meinel and Meinel [1] indicate that collector extraction efficiencies in the range from 80 to 90 percent should be possible. An analysis by Pope and Shimmel [8], as well as Kreith [9], indicate that at 1,000 to 1 concentration, and absorber temperatures near 2,000°K, the combined efficiency of the mirror and absorber may be about 60 percent. Some early experimental work is reported by Gilleter, et al. [9], who produced and tested a 3 ft. diameter mirror which showed that at a 1,500 to 1 concentration, the overall efficiency was 62 percent. Based on work in the early 1960's, McClelland [10] reported that collectors weighing 0.3 lb/ft^2 and having efficiencies of 70 percent at absorber temperatures of 1700°C was possible at that time.

It was recently reported [11] that the parabolic concentrator design has many attractive manufacturing cost factors and may be the only practical design for high concentration ratios. This report [11] gives preliminary cost estimates for the capital cost of $40 per m^2 for the concentrator shell and lining, support structure, control and sensors and drive, and installation

Thermionic Converters

One of the most important components of this proposed solar energy conversion system is the thermionic converter. In considering the use of thermionic converters, it must be realized that efficient conversion of solar energy into electrical energy requires high temperatures, i.e., in excess of 2,000°K. Thus, the converter must operate in conjunction with a solar concentrator which has a concentration ratio of the order of 10^3 to 1. Fortunately, thermionic converters have received a great deal of attention relative to their use in space applications since about 1956 [12]. In the period of 1958-60, Hernquist [13,14] and his colleagues at RCA, designed and constructed a solar thermionic converter system which delivered 6 watts at 6% efficiency. The electrical power density for this device was approximately 19 watts/cm^2. The converter in this system was a glass envelope device which was designed in a fashion similar to that used in vacuum tubes.

In subsequent years, a large number of researchers [15] have steadily improved the performance of thermionic converters by introducing many innovations in the design, types of materials and quality of materials.

The introduction of chemical vapor deposited [16] cathodes and anodes has greatly increased the power output and lifetimes of thermionic converters. In 1970, Clemot [17] et al. reported on the test results of a Cesium-seeded device which had a measured efficiency of 12.5% with an output of 7.5w/cm^2. The device operated continuously with no degradation in output for 6300 hours; it finally failed after 9,000 hours. This and other experimental evidence indicates that devices can be constructed which will function for three or four years in a solar conversion system.

Further, there is every reason to assume that more efficient devices will be constructed in the future. Since the thermionic converter is basically a heat engine, its efficiency is Carnot cycle limited and estimates [16] have been made that one can reasonably expect to eventually construct devices which have 35-40% electrical efficiency. Hotsopoulos [16] et al. have already demonstrated efficiencies in excess of 20% with power densities in excess of 20 w/cm^2.

The purpose of the preceding discussion is to point out that the technology of thermionic converters has progressed to the point that they can be utilized economically in our system. It has been demonstrated that a terrestrial-based system utilizing parabolic reflectors can provide sufficient energy to heat the thermionic emitter to 2000°K with 10^3 concentration ratios. This would indicate a heat flux of approximately 100 watts/cm^2 at the emitter. Existing thermionic converters can easily handle these power levels.

The system we are proposing to design and construct will require the focusing of the sunlight upon a black body adsorber which is attached to the emitter of the thermionic converters. A similar system has been proposed by Martini [18,19] for use in fossil-fuel fired converters.

Hydrogen Generation by Water Electrolysis

The low voltage-high current characteristics of thermionic converters are well matched to the power input requirements of water electrolyzers.

Currently available industrial electrolyzers with lifetimes in excess of 20 years, can produce 99.8% pure hydrogen at 200 atmospheres and 84% efficiency, using current densities of 1500 a/m^2 at 2.0 v per cell. The ability to operate at high pressures increases the cell efficiency while simultaneously eliminating the need for compressors. An electrolyzer capable of storing energy in the form of hydrogen at the rate of 100 KW would occupy less than 2 m^3.

The detailed reactions occurring at electrolyte-electrode interfaces are not fully known. For the electrolysis of water in alkaline solutions, the overall chemical reactions occurring at the two electrodes are:

$$2H_2O + 2e^- - H_2 + 2OH^- \quad \text{(Cathode)}$$

$$4OH^- - 2H_2O + O_2 + 4e^- \quad \text{(Anode)}$$

The equilibrium cell voltage at standard temperature and pressure is 1.229V. The standard change in free enthalpy for the combined reactions is -56,690 cal/mole.

The electrolyte usually consist of 15-25% NaOH or 25-35% KOH solution. Acidic electrolytes are normally not used because of corrosion problems. Electrodes and catalysts are chosen to minimize each half-cell overpotential. Iron is used as the cathode electrode because of its low hydrogen over-voltage, low cost and mechanical properties. Nickel-plated steel is used as the low overvoltage anode because nickel becomes resistant to chemical attack by nascent oxygen. Operation at increased pressure improves the efficiency by reducing the gas bubble size at the electrodes, thus reducing the overpotential. Increased temperature improves the electrolyte mixing.

Industrial cells of the unipolar tank and bipolar filter-press type have been in operation since the turn of the century [20,21]. Filter-press cells typically operate at current densities of 1500 a/m^2 and terminal voltages of 2.0-2.5 volts. Cells can be operated from 60°C and atmospheric pressure to 95°C and 200 atmospheres. The energy requirement at rated capacity and atmospheric pressure is typically 4.0 KWH/m^3 of hydrogen at STP. This corresponds to an energy conversion efficiency of 74%. Currently available pressurized electrolyzers operate at 84% efficiency.

A developmental water electrolysis process uses porous nickel electrodes separated by a thin asbestos matrix that contains an aqueous KOH electrolyte. The operating current density and voltage are 8,000 a/m^2 and 2.0 v with an overall efficiency of 83%.

CONCLUSION

In conclusion, we feel that the technology base exists which would allow the design and fabrication of the system present here. The system will be economically competitive with existing energy production methods (See Fig. 4) and will have the added advantage of being located "down on the farm."

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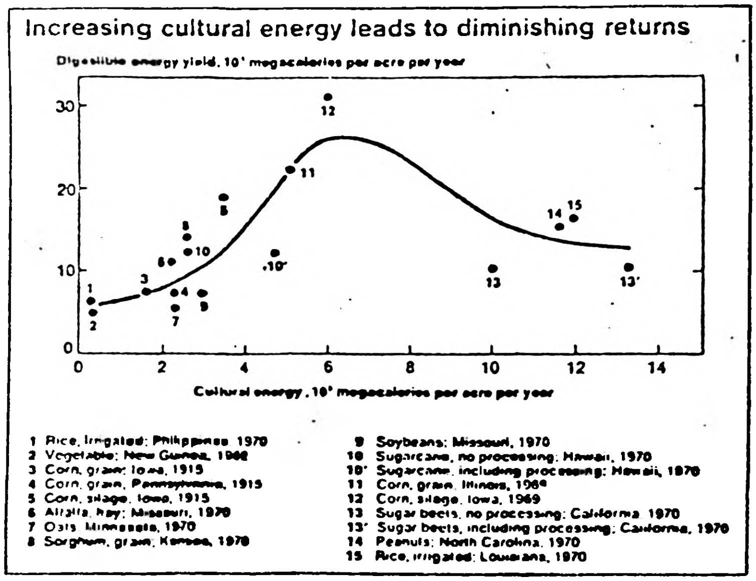


Fig. 1. Energy Expenditure For Various Crops

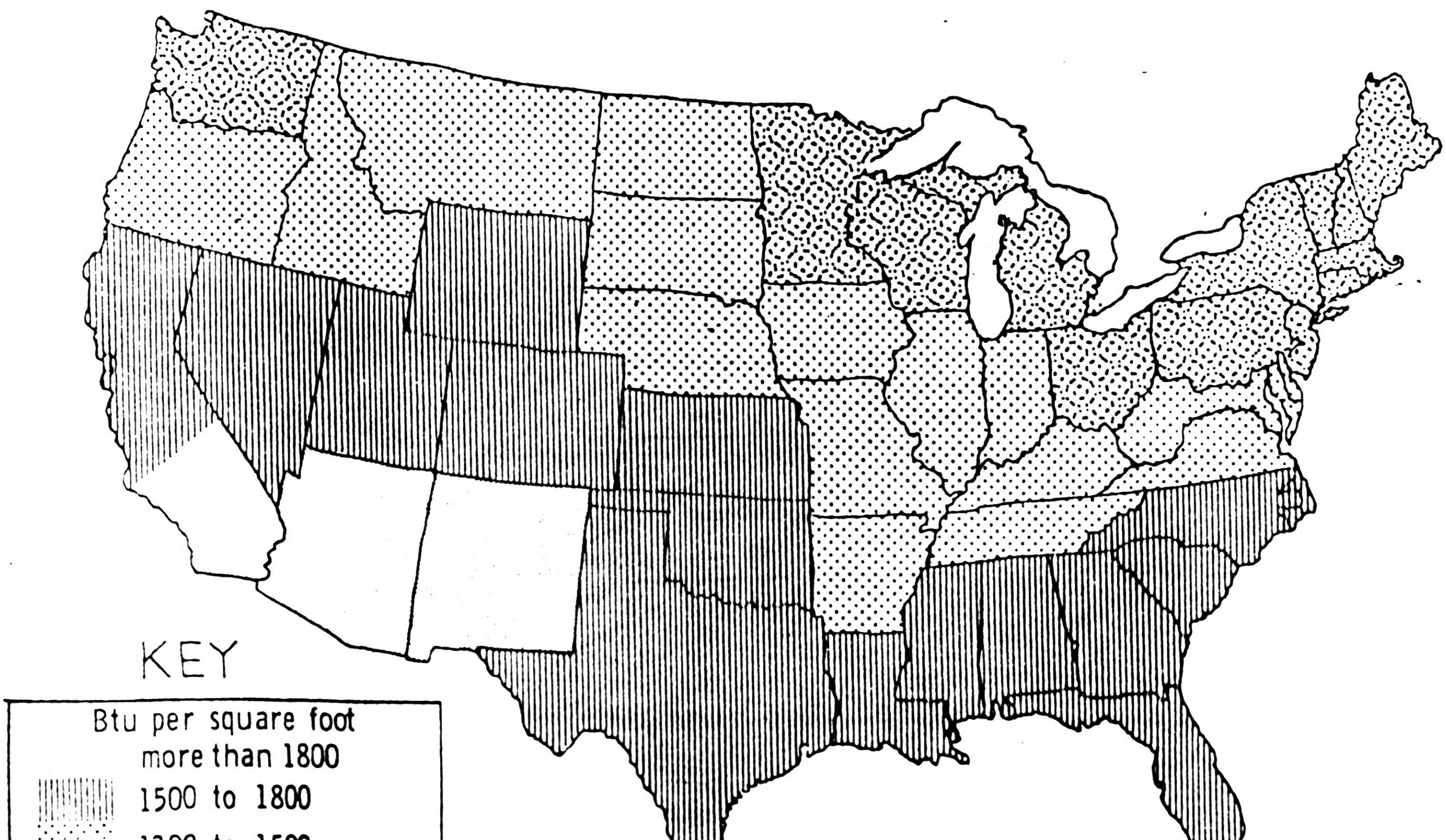


FIG. 2. Annual Mean Daily Solar Irradiance

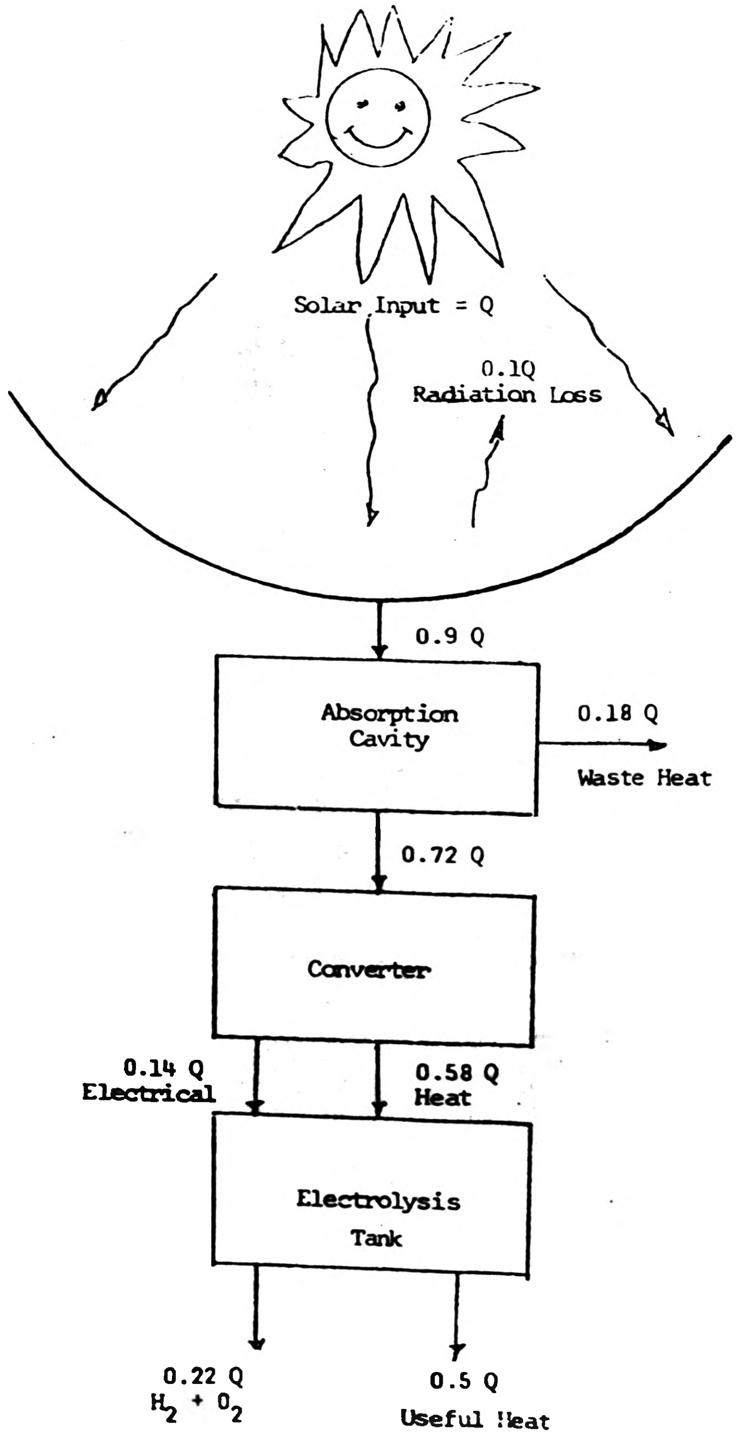


FIG. 3. Solar Hydrogen Production System

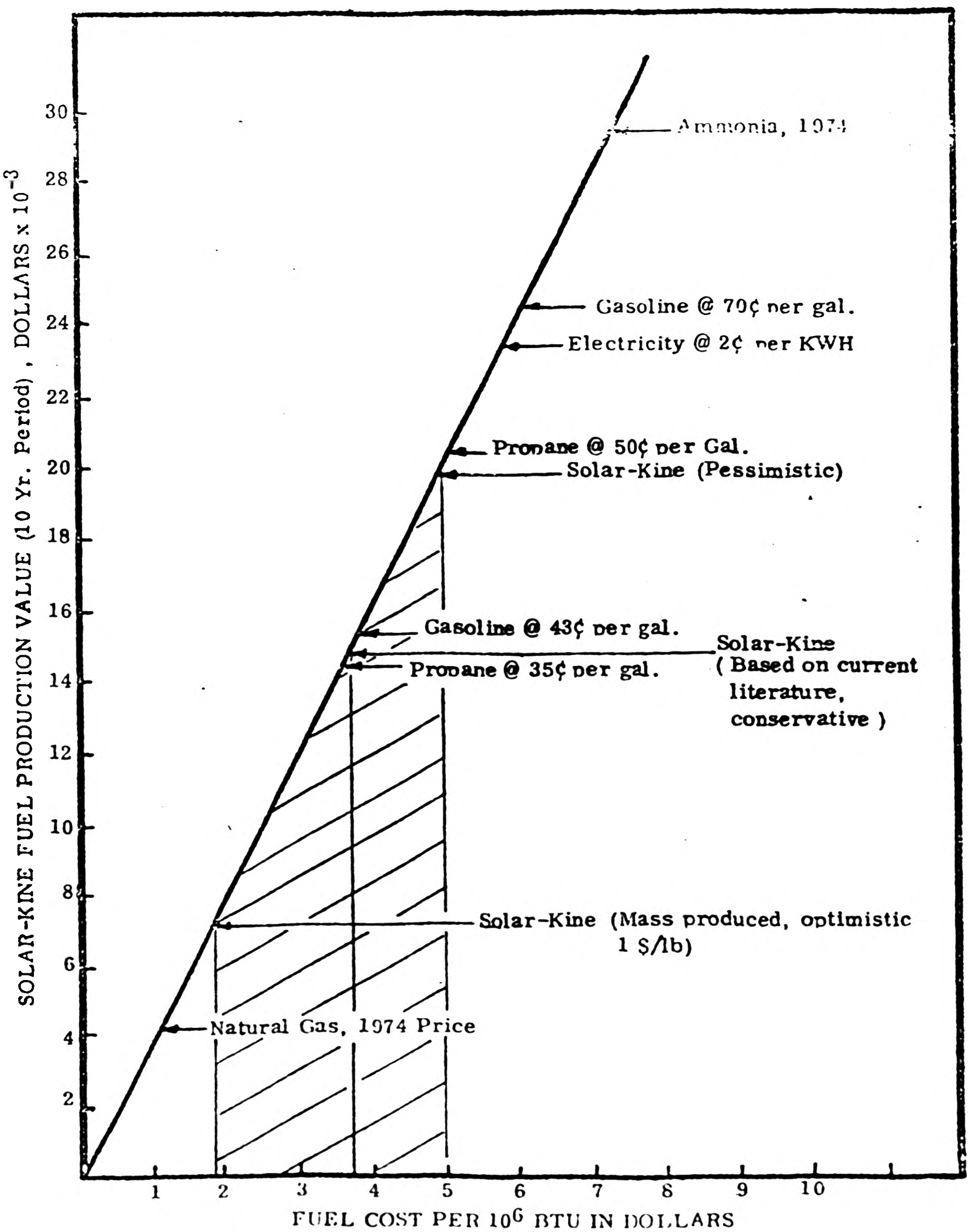


Figure 4. Cost Analysis of the Solar-Kine Based on the Replaced Fuel Value

FLAT PLATE COLLECTOR DESIGN FOR THE CENTRAL U. S.

Joseph T. Zung
Department of Chemistry
University of Missouri-Rolla
Rolla, Missouri

Abstract

An efficient design for both heating and cooling of an average sized residence is presented. The main source of energy is derived from a large roof top flat plate collector built into the roof structure of the house. The amount of solar energy collected is stored in a combination of hot air and hot water storage system located underneath the house. An auxiliary electric heating coil is built into the solar heating system for use in any extended period of cloudy and inclement weather. The system is so designed as to satisfy the two key requirements for any successful solar house, namely, ECONOMIC FEASIBILITY and RELIABILITY. Materials used for collectors, working fluids, storage equipment, etc. are readily available in lumber yards. The cost of the solar system is kept to a minimum and can be compensated by architectural design and construction savings through the use of the collector itself as the main roof structure. It is believed that the cost of this solar house will not exceed that of a residential dwelling of comparable size and quality in Missouri. However, the saving in fuel consumption will be substantial, up to 80%.

Introduction

The amount of solar radiation reaching the U. S. daily is more than a thousand times larger than our daily energy consumption. However, in the past, sunlight as an energy source has not been tapped significantly for performing mechanical work, for the following reasons:

(1)- Sunlight is not continuous at any location. Energy collected during the sunlight hours must be stored for night use;

(2)- Conversion of sun energy into mechanical and electrical work is very inefficient. The conversion efficiency for the most modern photocells is 10-15 % at best, and the maximum theoretical efficiency has been calculated to be only 24%;

(3)- Solar energy has a low intensity. It requires about 50 square miles of solar collector area to generate 3,500 megawatts of electric power, just enough to satisfy the electrical needs of a city of the size of Los Angeles.

On the other hand, solar energy is plentiful and pollution-free. The only form of pollution is the esthetic pollution arising from extensive collector areas, which could destroy the beauty of our landscape.

Recent research has been concentrated on two main objectives: to provide heat and electric power to the nation through utilization of solar energy. Ambitious programs have been initiated to collect high temperature solar energy to generate electricity. These programs often require elaborate systems and designs to collect the sun's energy and to convert it into electrical power. To use solar energy to heat and cool residential homes, on the other hand, does not require expensive equipment. Present state of the art is quite adequate to make solar heating and cooling very competitive with conventional methods. In this paper, I would like to discuss the merits and promises of such a house.

Design Philosophy

Technology for using solar energy for water and space heating has been worked out for years. Recently, solar-powered houses are springing up in Delaware, Colorado, Florida, and Pennsylvania, with plans for others on the drawing boards. Our objective in this program is to design and build a solar house that meets all specific requirements for the climate and other geographic characteristics of Missouri and surrounding States in the Mid-West. Further, we hope to meet some of the most basic requirements for public support and acceptance of such a house. To gain a wide public support and acceptance, it is imperative that we give the public whatever they want. But usually, when we present to the people a prototype solar house, they often find the following objections:

(1)- Solar houses are at best some oddities, with unacceptable architectural design. They are not the kind of homes people would like to live in.

(2)- Solar houses are too expensive. It is imperative that we must keep the cost of the solar system down to a minimum. For example, a $10,000 solar system to be added on to the current mortgage of the house would amount to more than $100 extra in mortgage payment, which is more than what most families pay for their utilities in the coldest months.

(3)- Solar systems are not reliable. It is evident that the general public wants winter and summer comfort with the assurance of back-up systems, and without frequent costly repairs.

Furthermore, since solar energy is diffuse and of a very low intensity, the cost of a solar system would rise exponentially with the heating and cooling loads and with the degree of self-sufficiency in providing all the power requirements of the house. Thus it would be impossible to keep the cost down if, for example, we must provide electricity for cooking and light, since the photovoltaic cells are still the most costly components in the energy conversion process. To reduce the heating and cooling loads as much as possible, we must follow as closely as possible all the energy saving tips in home construction. They are listed as follows:

1)- Siting:
- -Built your house on the sunny side of a hill, tucked into the hill;
- -Keep all surrounding trees, especially to the North for wind breakers and to the West for shielding the hot sun in the summer;
- -Face short walls to the North, preferably without any windows;
- -Face South all living rooms, kitchen, and family rooms, face East all bedrooms.

2)- House Design:
- -Build your house with a minimum amount of exterior walls for a maximum living area. A circular house would be best, but it is usually more expensive to build, due to increase in labor cost. The next best design is a two-story, square or rectangular in shape.
- -The first floor must be well insulated from the basement or crawl-space.
- -Design all living area (kitchen, living room and family room) open to a large expanse, for it is

much easier to heat a large room than several small ones.

-Provide good ventilation under roof and in the attic.

3)- Materials:

-Use light colored shingles;

-Use a minimum amount of windows, all windows must be of thermopane double insulating glass;

-Provide at least 10" insulation on ceiling and 4" or 6" with vapor barrier on outside walls;

-Heat ducts must be run inside the insulated area;

-Use 5/8" wood siding and caulk all cracks;

4)- Location of appliances:

-Use heat retrieval, open air cycle heating systems;

-Install exhaust fans in all bathrooms and kitchen;

-Use heat from the fireplaces to heat all the rooms in the house, including the upstair bedrooms;

-Use glass firescreens on all fireplace openings

-Place stove, washer, dryer away from exterior doors and walls;

-Do not place refrigerator near heat registers or in direct sunlight areas.

With the above precautions, we are able to reduce the power load of a standard three bedroom house by one half, as shown in Tables 1 and 2.

After surveying the popular opinion on house design and styling, we have arrived at the conclusion that most American families still cherish a single detached family homes of early Colonial or New England architecture, similar to the one shown in Figure 1.

Solar Collector

In the Mid-West, the amount of sun energy that could be collected at noon hour varies from 280 to 300 BTU/hr-sq.ft. A roof-top solar collector of 1,000 sq.ft. in area would collect enough energy in one good sunny day to heat the proposed house for at least three or four cloudy days. The collector is built as a part of the roof structure so that substantial savings on plywood and shingles may be used to compensate for the cost of sheet metals and glass or plexiglass cover. Details of construction is given in Figure 8. The collectors are fabricated of wooden frames and utilizes black-painted corrugated metal plates as the absorbers. To prevent breakages and to minimize maintenance costs, instead of the glass cover one may use a nylon-reinforced solar resistant, plastic-fabric material .The total annual heat collected, as shown in Fig.2, is only about 6% short of the power requirement in the months of December and January but more than enough to cool the house in the summer months.

Heat Storage

With the reduced heat load (276 BTU/hr/^{o}F) of the house, it requires only about 2.5×10^{5} BTU/day to keep the inside temperature at 70 ^{o}F when the outside temperature is at 20 ^{o}F. In order to store 1 million BTU for four days use, we need about 50,000 lbs. of water or a volume of 1,000 cubic feet. A concrete storage tank (10' x 10' x 10') insulated with 6" fiberglass bats may be constructed in the basement level. Additional heat storage can be obtained by using rock, but it will require twice the volume (about 2,000 cu.ft.) of water to store 10^{6} BTU. We have discarded the use of Clauber's salt or other chemicals in order to keep the cost down to a minimum. An auxiliary storage tank (600 gallons) is used for hot water in the winter and as the condenser-evaporator for the NH_3-H_2O air conditioning system in the summer.

Heating and Cooling

Water is circulated from the storage tank through the collector loop at a rate of 10 lbs/sq.-hr, by a circulating pump controlled by a comparative-type thermostat which will energize the pump when the collector temperature exceeds that of the storage tank by 5^{o}F. The heat energy, through a heat exchanger, is carried through the living area in the form of warm air by a fan-coil unit having a variable speed blower motor. An auxiliary electric heating coil is inserted into the main plenum which will be energized when the air temperature falls below 68 ^{o}F. Domestic hot water is supplied through a coil immersed in the smaller water tank. As shown in Fig. 5, the fireplace is used as an auxiliary heating system. In order to save energy from the solar system, the warm air from the heat storage is distributed to all the rooms through the plenum surrounding the fireplace so that when the fireplace is being in use, the main blower motor of the main line is shut off when the air temperature around the fireplace is above 72^{o}F.

For summer cooling, we use a NH_3-H_2O absorption air conditioner with the two water storage tanks as heat source and evaporator-condenser.(Fig.4)

The over-all diagram of the heating loop is shown in Fig. 3 and Fig. 7. The floor plans shown in Fig. 5 and 6 give the locations of heat registers around the firplace into each room.

Cost Analysis

Based on the labor and material market of Rolla, Mo. the cost of the solar collector (corrugated metal roofing material and glass or plastic cover) is about the same as the cost of plywood and shingles in a standard house. The only extra cost involved would be the labor cost for installation. The heat storage tanks would cost about$1,000 while the duct work and the air conditioner is about the same as an electric furnace and air conditioner in standard houses. Even if we include the extra costs of thermopane windows and insulation, the total cost of our solar house would not exceed that of a standard house by more than $2,000. This can be quickly recovered through savings in power consumption and utilities bills at a rate of $50-75 per month, or roughly in about two and half years.

Conclusion

It is feasible in the immediate future to build an economical and reliable solar house which will supply at least 75-80% of energy for heating and cooling with a minimum additional cost to the home buyer. The key element of such a house is to conform with the natural environment in minimizing energy needs and to use only cheap, commonly available building materials for heat collection and storage. Uses of auxiliary and supplementary heat sources must be incorporated into the design and construction of the house. Special attention must be paid to the esthetic and architectural values of the general public.

Table 1 - Heating Load

Exterior Areas	Standard House		Thermal House	
	U value (BTU/hr/ft²/°F)	Heat Loss (BTU/hr/°F)	U-value (BTU/hr/ft² /°F)	Heat loss (BTU/hr/°F)
1460 sq.ft.exterior wall	0.07	102	0.04	58
Windows, 140 sq.ft.glass	1.13	158	0.45	63
Ceiling, 1700 sq.ft.	0.068	116	0.027	45
Floor, 200 lin.ft.slab perimeter	0.81	162	0.55	110
TOTAL HEAT LOSS/°F		538		276

Note: Standard house specifications: R11 insulation on walls,
R19 insulation on ceiling

Table 2 - Cooling Load

Exterior Areas	Standard House		Thermal House	
	U-value & T	Heat Gain	U-value & T	Heat gain
Exterior Walls, 1460 sq.ft.	U=0.07 T=18.6°F	1900 BTUh	U=0.04 T=11.3°F	660 BTUh
Ceiling, 1700 sq.ft.	U=0.068 T=31.0°F	3580	U=0.0267 T=23.3°F	1057
Windows, 140 sq.ft.	U=1.13	3220	U=0.45	2380
TOTAL	23 BTUh/sq.ft.	8700 BTUh	17 BTUh/sq/ft/	4097 BTUh

Note: Temperature for the summer is taken as 95°F outside and 75°F inside
Windows for standard house are of single pane glass and for thermal house are of thermopane double insulating glass, Andersen

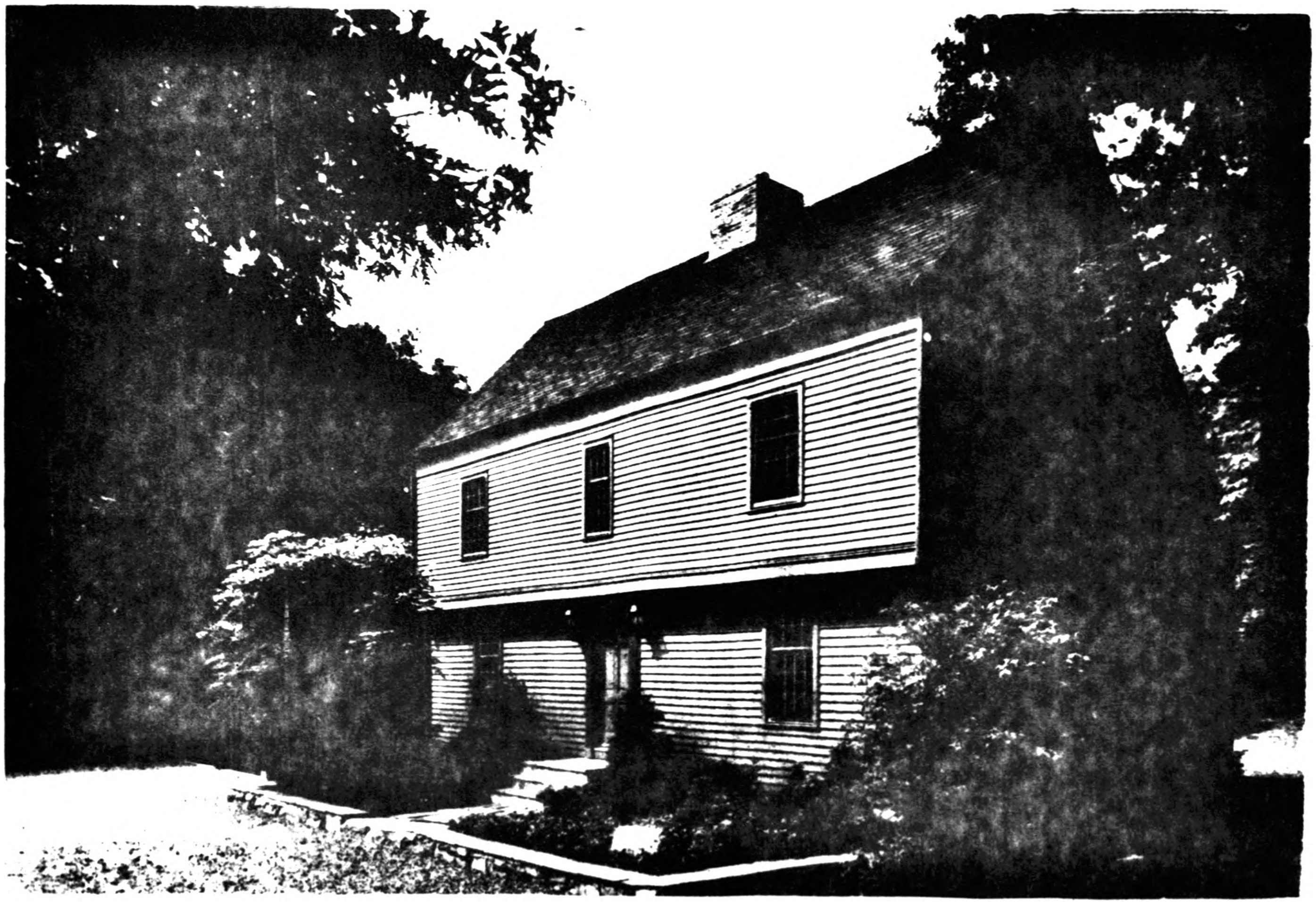


Figure 1. Front Elevation of a Salt-Box House

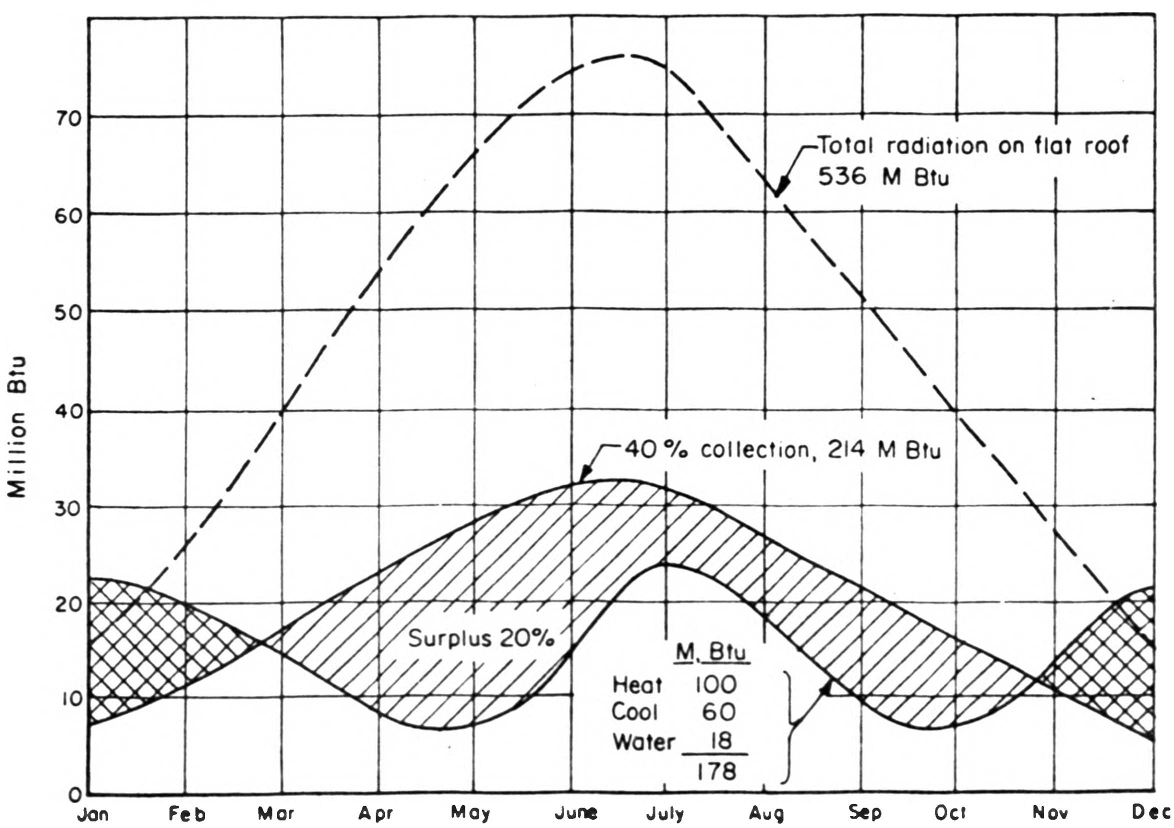
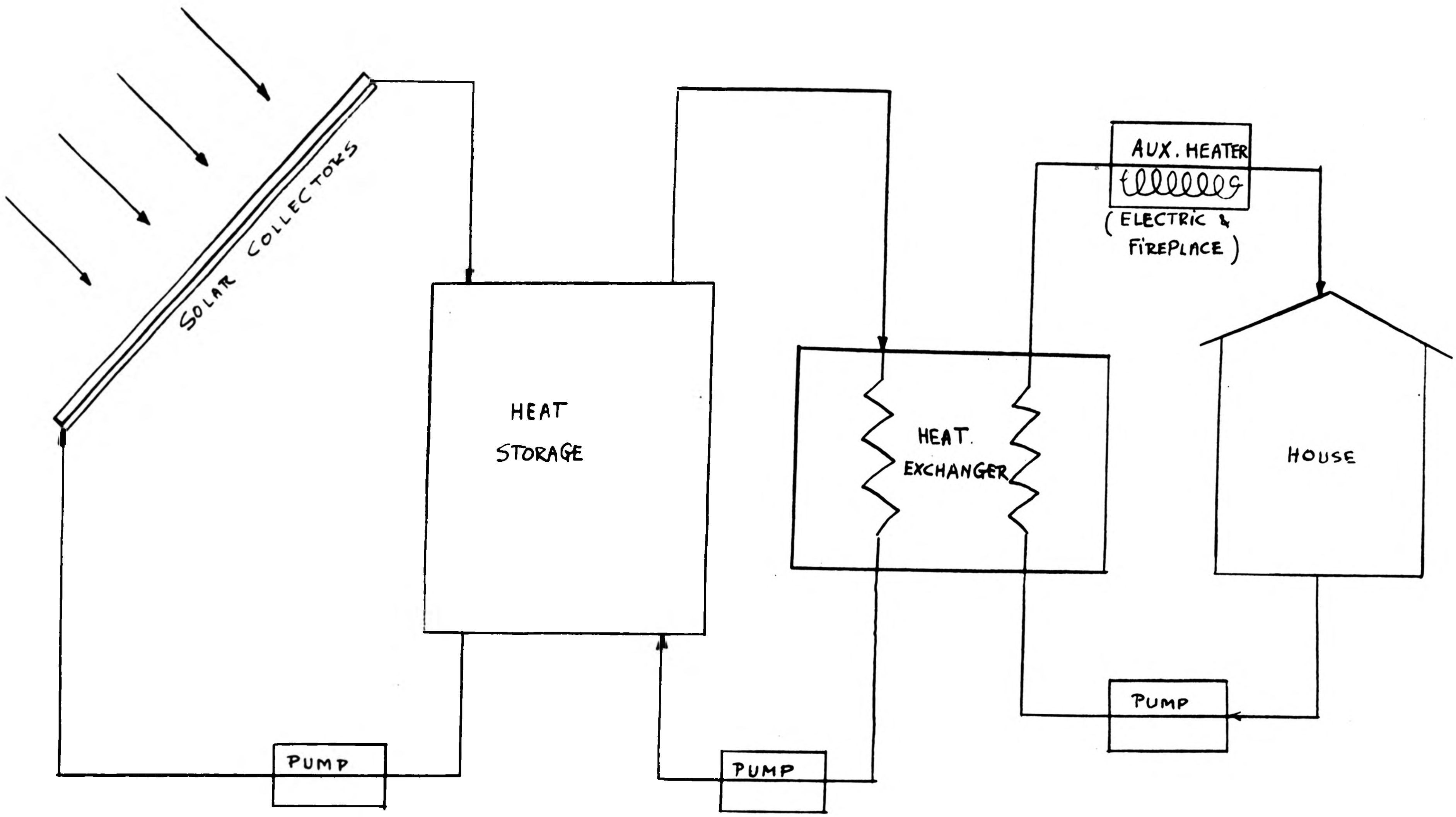


Figure 2.


SOLAR COLLECTORS
HEAT STORAGE
HEAT EXCHANGER
AUX. HEATER
(ELECTRIC & FIREPLACE)
HOUSE
PUMP
PUMP
PUMP

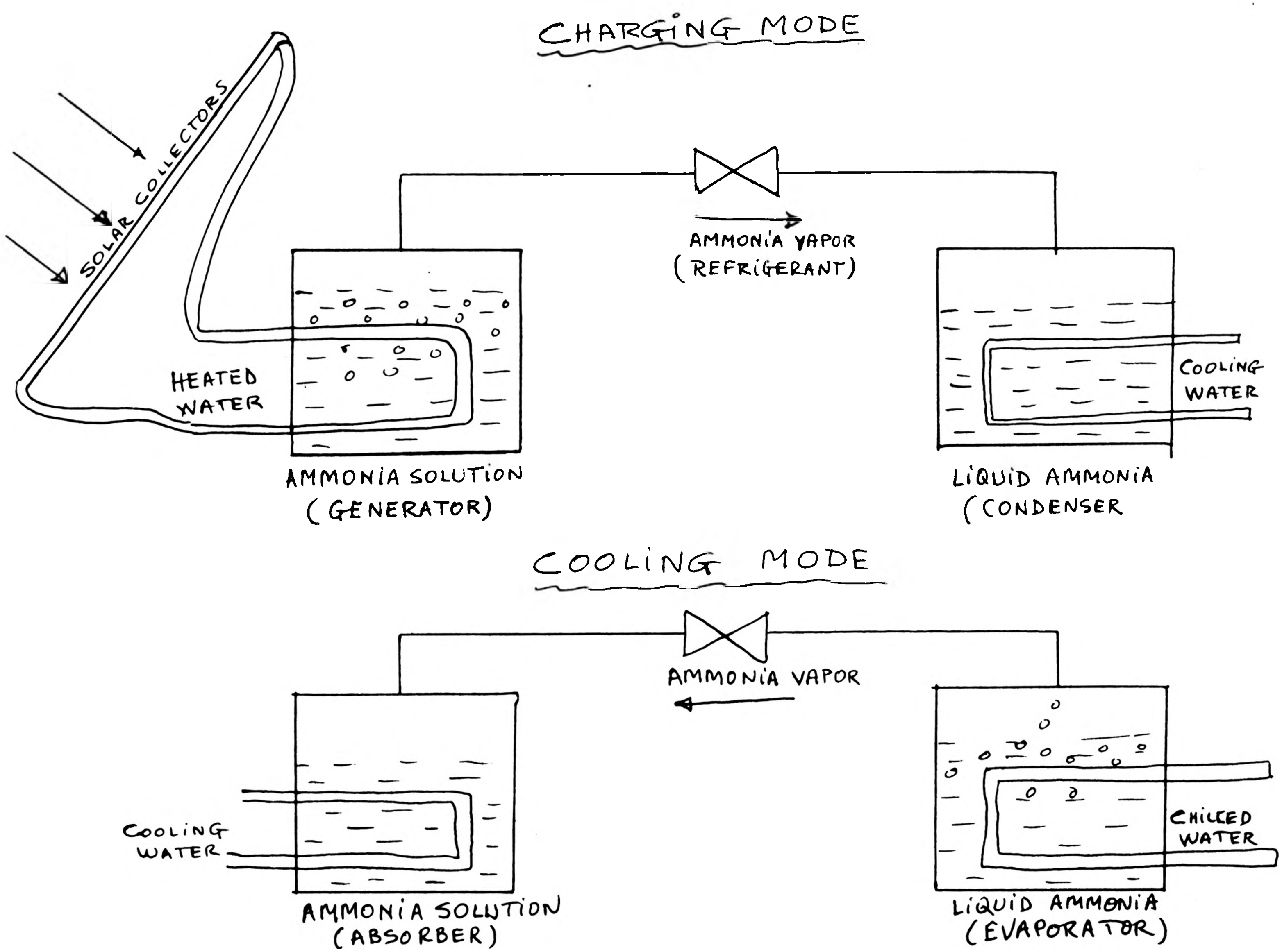


Figure 4. Schematic diagram for a NH_3-H_2O absorption air-conditioner

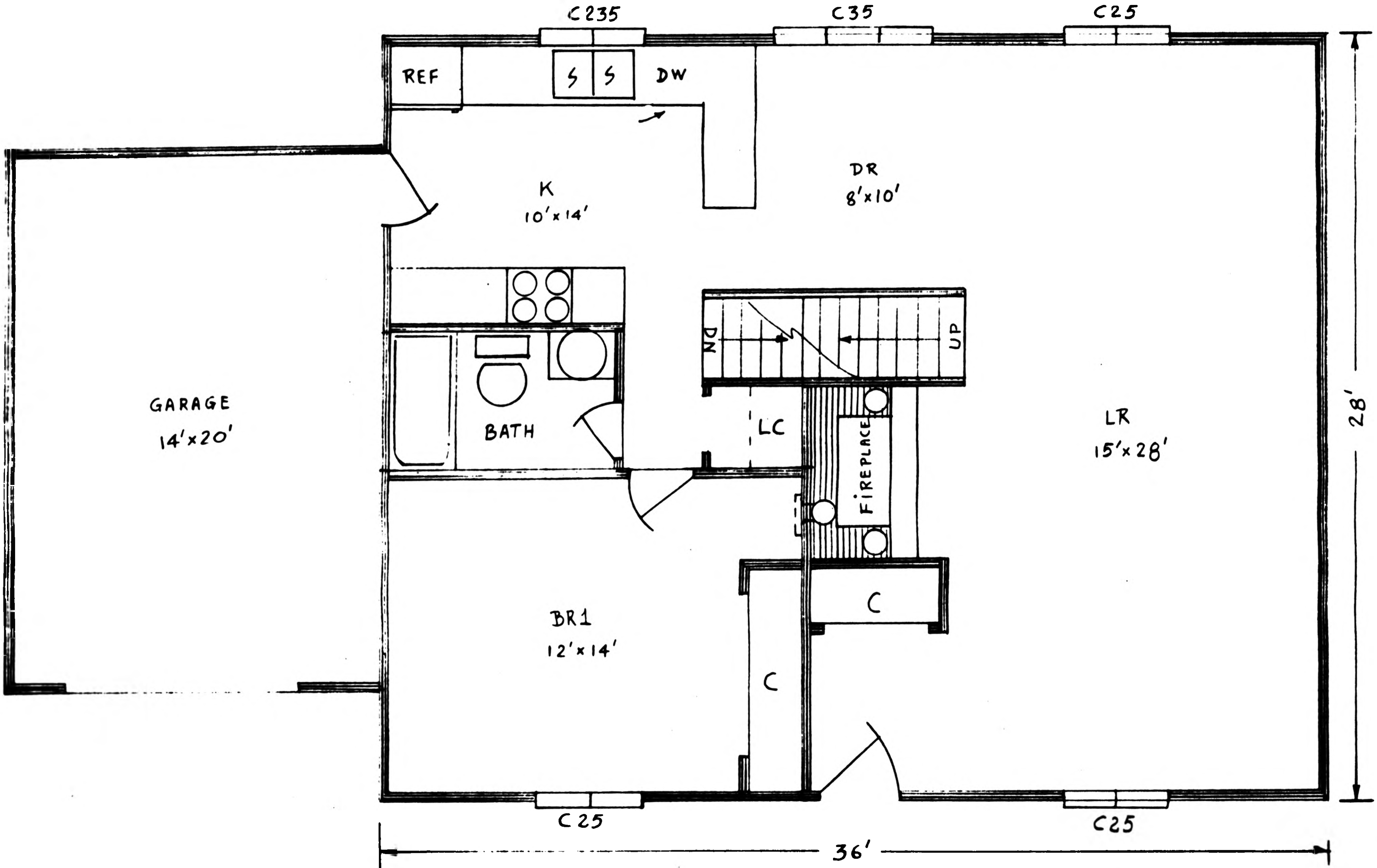


Figure 5. Floor plan for the 1st level

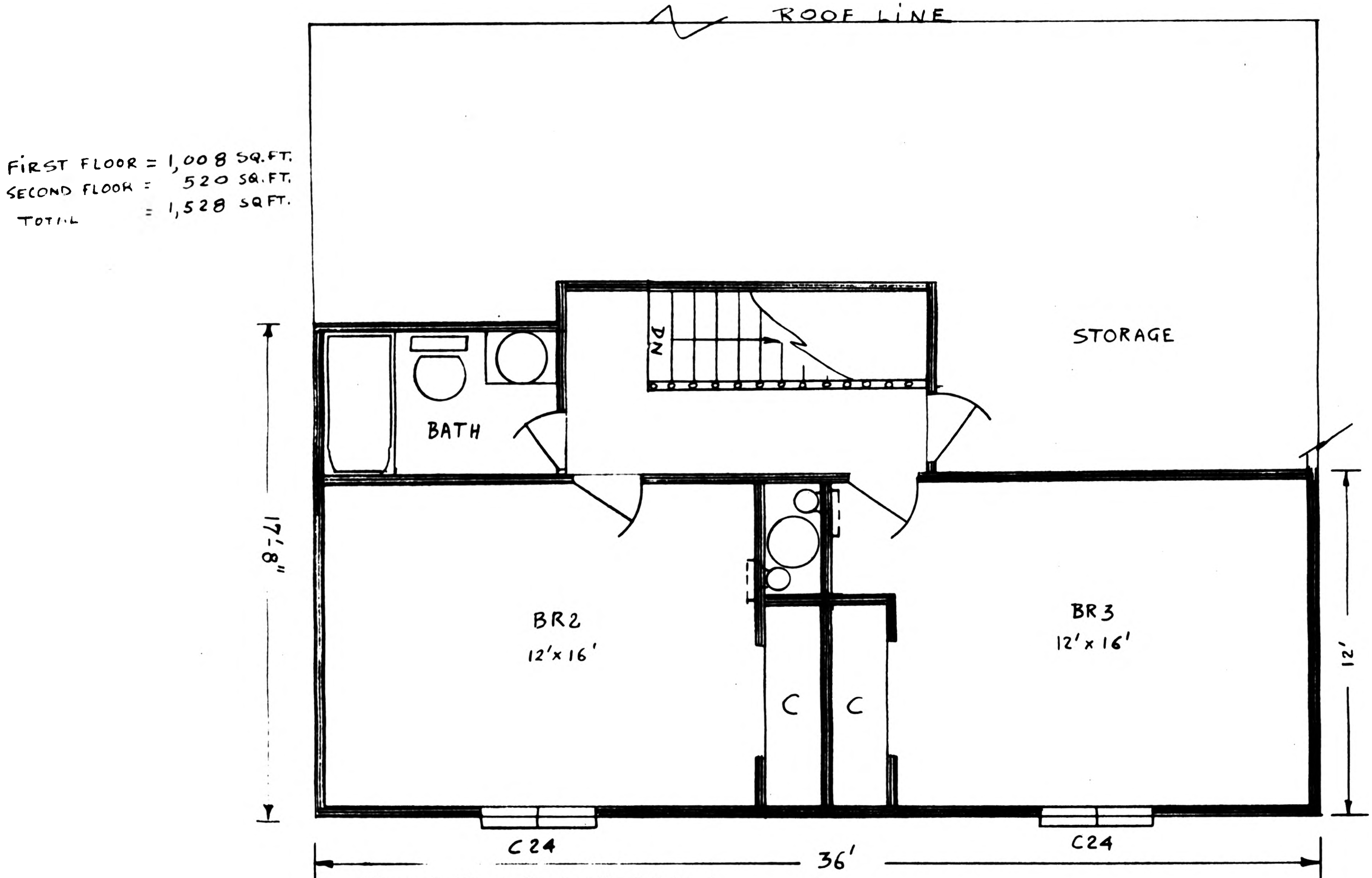
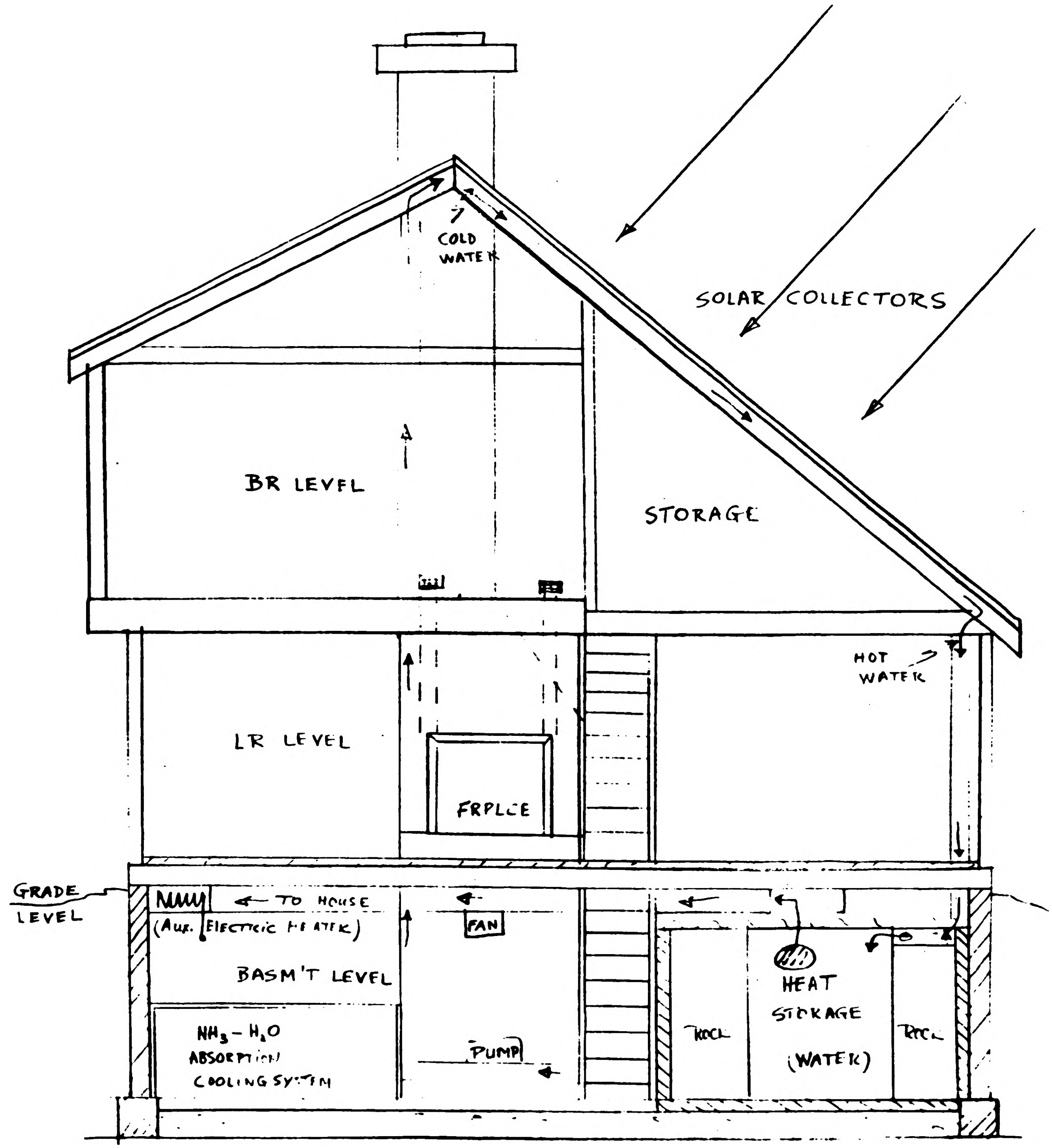


Figure 6. Floor plan for the 2nd level


COLD WATER
SOLAR COLLECTORS
BR LEVEL
STORAGE
HOT WATER
LR LEVEL
FRPLCE
GRADE LEVEL
TO HOUSE
(AUX. ELECTRIC HEATER)
FAN
BASM'T LEVEL
HEAT STORAGE (WATER)
ROCK
ROCK
$NH_3 - H_2O$
ABSORPTION
COOLING SYSTEM
PUMP

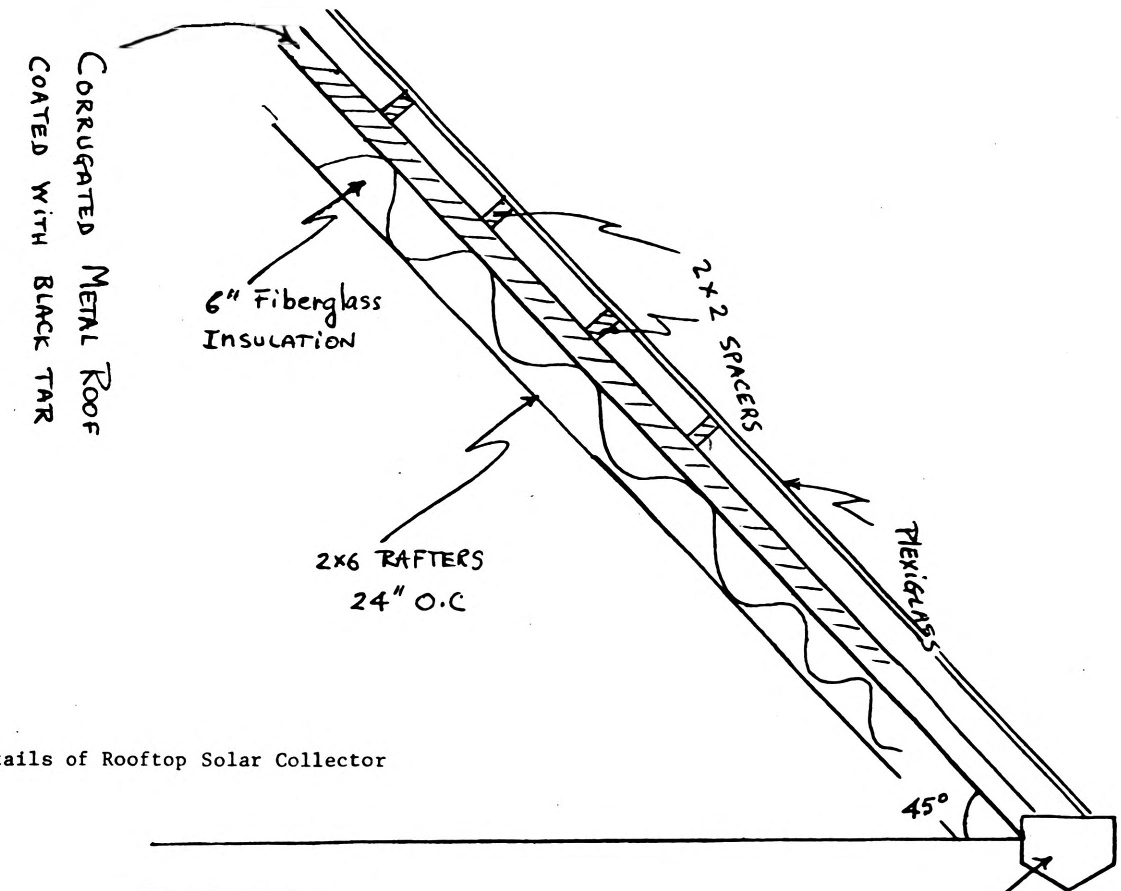


Figure 8. Details of Rooftop Solar Collector

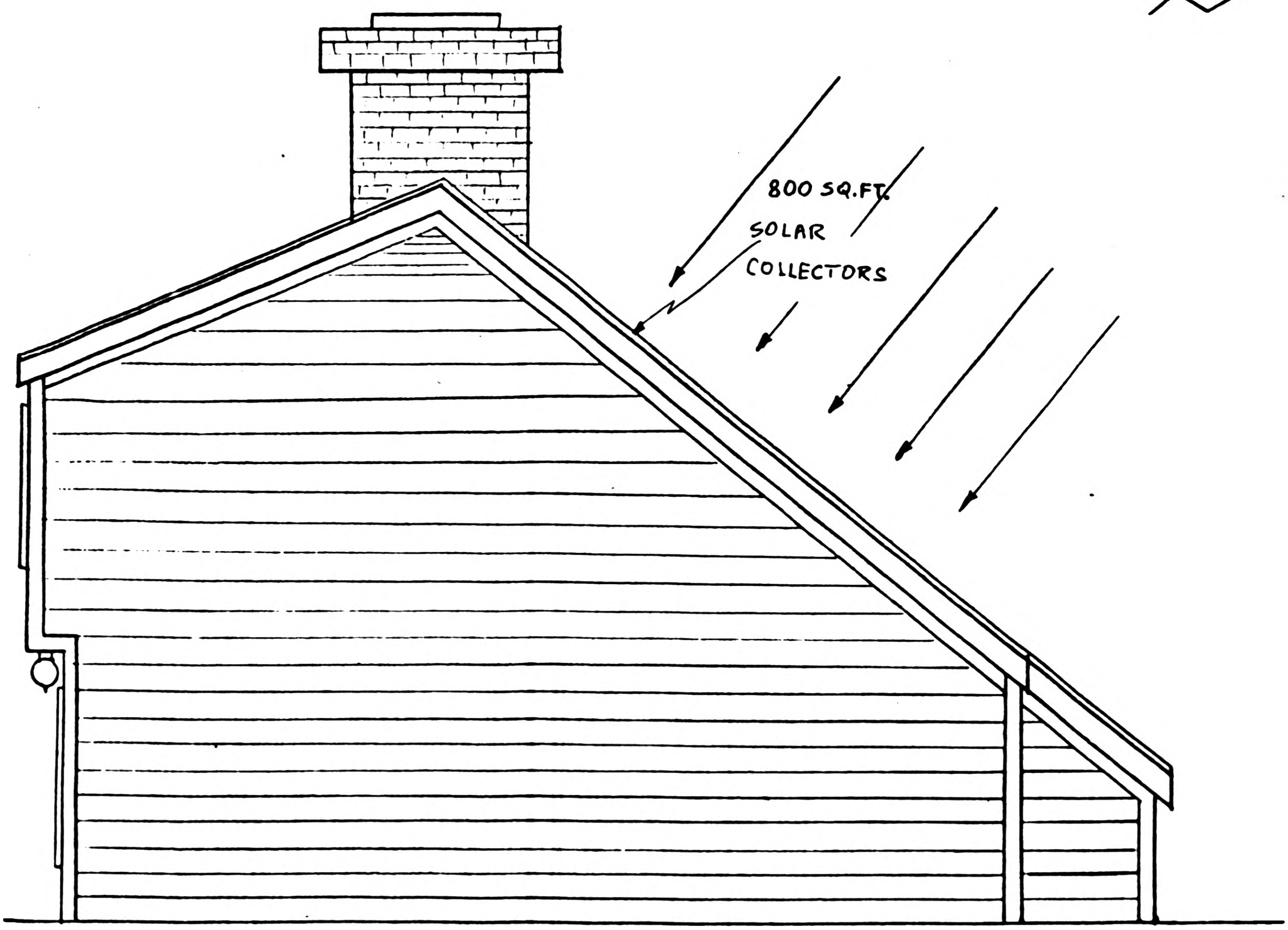


Figure 9. Side Elevation of the Solar House

Figure 10. Front Elevation of the Solar House

IV - CHEMICAL ENERGY

CHAIRMAN:
JAMES L. GADDY

THE ENERGY PROBLEM - CRUDE OIL

J. A. Marshall
Shell Oil Company
Wood River, Illinois

ABSTRACT

This paper discusses the national energy problem as it affects the demand for and availability of crude oil. Forecasts of energy demands to 1990 have been made based on population trends and changing life styles in the USA. Projections of energy supplies show a rapidly increasing gap between supply of crude oil and demand for crude oil from the early 1970's through 1990. The need for imported crude oil to supply the forecast deficit is discussed. The political and economic implications of these imports are also discussed. The need for refineries, port facilities, tankers, and pipelines are presented. Finally, recommendations are made for actions to be taken to meet our energy needs.

I. INTRODUCTION

Many Americans first became conscious of a gasoline supply problem during the summer of 1973. For the first time, spot shortages of gasoline appeared in a number of areas, and motorists found they were unable to buy all the gasoline they would have liked. In the fall of 1973, when the Middle East oil exporting countries imposed an embargo on crude oil to be shipped to the United States, shortages of gasoline, home heating oil, aviation turbine fuel, and other products of the petroleum refinery threatened to become acute. The government responded to the crisis with alacrity and established allocation systems so we could all share the shortage. Motorists have become frustrated and angry at having to wait in line for gasoline and at finding they could not buy all the gasoline they wanted.

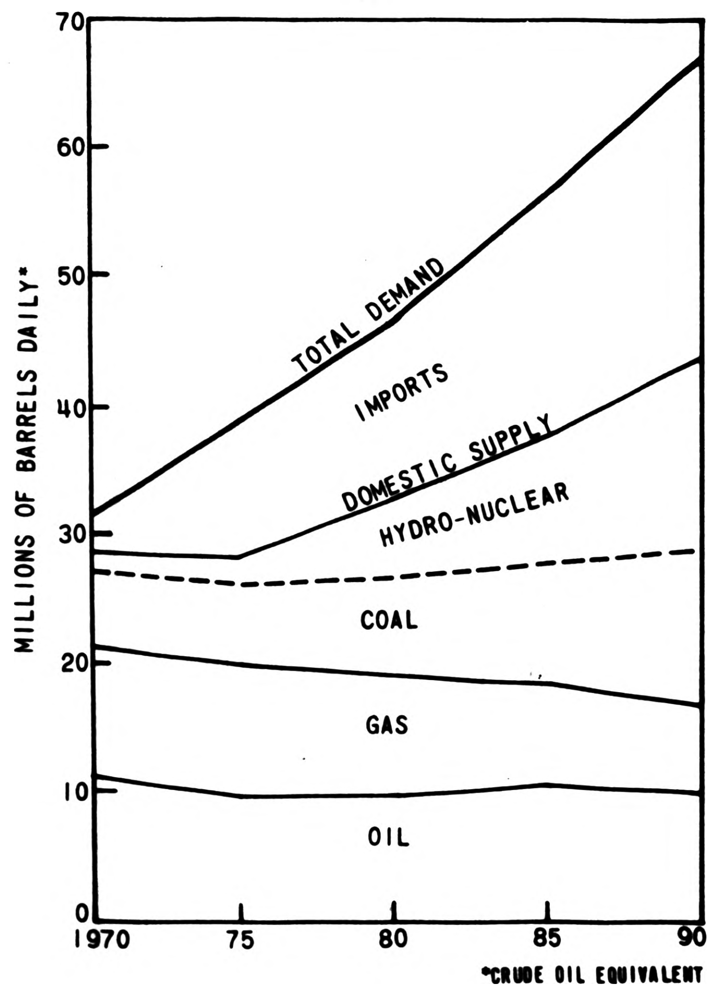
Despite these shortages, however, total energy consumption in the USA in 1973 actually increased 4.8 percent over 1972. Consumption of fuel in the transportation sector increased 3.8 percent relative to 1972. Thus, even though the energy industry supplied more fuel in 1973, demand was increasing faster than industry's ability to supply. Let us examine the national energy situation in order to understand how the shortages came about and to project the future of crude oil and refined product supplies.

The U.S. energy gap from 1970 projected to 1990 is shown in Chart 1. It will be seen that total energy demand is predicted to increase steadily throughout the period while domestic supply remains relatively constant through 1975 and then increases modestly. The difference between demand and supply is projected to be made up of imports of crude oil and refined products. The large amount of imports may create intolerable strains on our balance of payments account with the rest of the world. The political and economic implications of the large dependence on crude oil imports have become painfully apparent to us during the recent Mid-East embargo.

Our examination of the energy supply and demand picture shows that only oil can supply the major part of the growth in the nation's energy needs for the next decade at least. At best, newly found domestic oil can just offset declines in older fields and therefore the additional oil needed will have to come from abroad. Some contribution towards supplying the energy requirement will come from nuclear sources towards the end of the 1970's, and this contribution will later accelerate.

CHART I

THE U.S. ENERGY GAP 1970-1990



II. THE ENERGY OUTLOOK FOR THE USA

Premises of the Forecast

The forecast on which this paper is based necessarily depends on various premises. The assumptions are as follows:

1. Population

There will be population growth at the rate of 1 percent per year. The most probable projection is based on the Census Bureau's Series E projections which give by 1990 an increase of 46 million people over the 1970 population of 205 million.

The post-World War II "baby boom" generation is now the 15-25-year age group. Between 1970 and 1990 they will increase the labor force from 86 to 115 million and the number of households from 63 to 90 million.

2. Economic Growth

There will be annual growth in real Gross National Product of 5.7 percent through 1975. The rate will then decline to 4.3 percent and after 1980 to 3.8 percent.

3. Oil Imports

The Oil Import Program will be revised so as to allow imports to satisfy the difference between domestic oil demand and production.

4. Natural Gas Regulation

It is assumed that regulatory control will be modified, with some increase allowed in wellhead prices to stimulate development of new supplies and to reflect the value of gas compared to alternative fuels.

5. Land Use Regulation

By 1975 the Federal government will develop new guidelines on land use within which states will develop their own plans. These will cater to the siting of energy facilities such as power plants and refineries.

6. Pollution Standards

Severe restrictions proposed for auto emissions will be adhered to and the control of sulfur emissions extended.

7. Technological Developments

The forecast takes into account foreseeable innovations. These include development of commercial stack gas scrubbing by 1977 and electric battery/fuel cell cars by 1985.

8. Transportation

Individual cars will remain the primary mode of transporting people but there will be a trend to smaller cars as costs escalate. The various forms of mass transit are estimated to have no major effect on motor gasoline consumption in the forecast period.

Aviation load factors will be about 55 percent from 1975 to 1990.

9. Residential

The average size of homes will decrease. More efficient home insulation will moderate space heating demand. The residential market will get preferential allocation of existing gas supply.

10. Energy Supply

Crude Oil

Estimates are based on two offshore lease sales totaling 1 million acres per year. North Slope crude from Alaska is premised to reach West Coast refineries in 1976 (This is now known to be optimistic). Full Alaska pipeline capacity will be reached by 1982. Oil will be available overseas to supply required imports.

Natural Gas

There will be a Mackenzie Valley gas line from the Canadian Arctic by 1978, to which Alaska North Slope gas will be tied in by 1980. Volumes of overseas liquefied natural gas (LNG) will be limited due to high costs and uncertainty of sources.

Nuclear

Nuclear development through 1985 is constrained by long lead times of 7-10 years. Thereafter, it will accelerate.

Coal

Long-term growth is envisaged. Environmental restrictions on strip mining will affect rate of short-term growth.

Unconventional Raw Materials

A major effort to develop coal gasification is expected. Shale oil and conversion of coal to liquid hydrocarbons are not projected as significant supply sources before 1990 principally because of technological problems, but also because high manufacturing costs will require a high market price for these synthetic energy raw materials. No other new sources of energy will become substantial suppliers before 1990.

U.S. Energy Demand

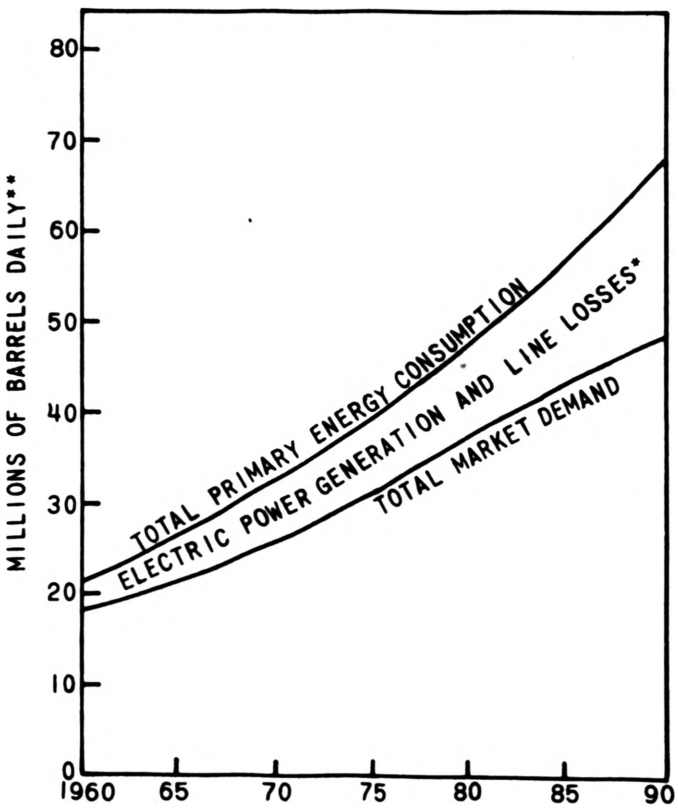
The United States - with one-sixteenth of the world's population - consumes one-third of the world's energy. We use more energy to heat and cool homes; we travel more miles and produce more goods than any other nation. Energy cooks our food, lights our way, and runs our machines.

Energy consumption more than doubled in the last 20 years. As shown in Chart 2, consumption will double again between 1970 and 1990, increasing from the equivalent of 31.8 million barrels of crude oil daily to 67 million barrels. The annual average growth rate, however, is predicted to be lower at about 3.8 percent.

The nation's energy is primarily used by five major markets: transportation, industrial, residential, commercial, and electricity generation. Of these markets, electricity generation, transportation, commercial, and (within industry) chemical, grow faster than total energy demand. Other markets grow more slowly. A particular feature of the U.S. energy consumption pattern has been the sharp rise (8.2 percent 1971/72) in the demand for distillate oils. This has been caused by various factors. Shortages of natural gas have led to switches to oil. Then there have been the effects of environmental and sulfur restrictions on the use of coal and residual fuel oil for electricity generation. This combination of circumstances has caused domestic distillate to be used increasingly for boiler heating.

CHART 2

U.S. DOMESTIC ENERGY DEMAND



*ALSO INCLUDES LOSSES FROM GASIFICATION AND LIQUEFACTION.

**CRUDE OIL EQUIVALENT

The Transportation Market

The overall growth of the transportation market can be seen in Chart 3. What is not clear from the chart is the important role motor gasoline plays in the total transportation picture. The annual miles driven by the average driver have been increasing linearly for the last 20 years. The prospect is that this will continue to be a highly mobile society, and therefore transportation will continue to be a major energy consumer.

Fuel consumption per mile is expected to increase significantly. Emission control and safety devices fitted to new automobiles will decrease average miles per gallon by about 15 percent during the late 1970's.

Battery and fuel cell cars are estimated to have no major impact before 1990. There may be 2 million such cars by 1985 and 6 million by 1990, but this will be less than 5 percent of the total car fleet.

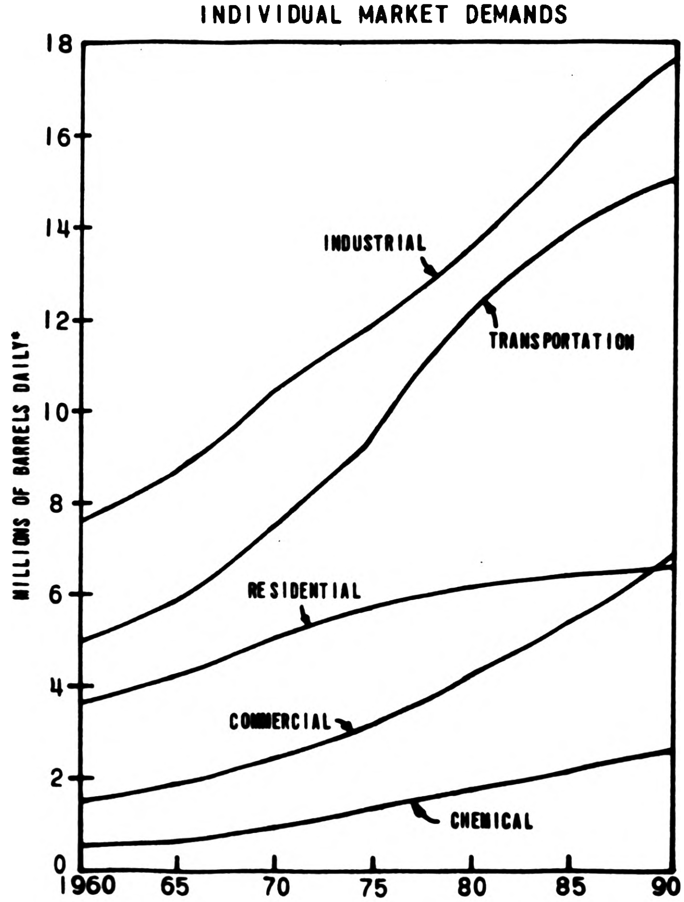
Aviation kerosene-type jet fuel has been a rapidly growing portion of the transportation market. Future growth rate is expected to decrease as market saturation occurs and as larger, more efficient aircraft continue to displace the present fleet. Seating capacities of aircraft have risen steadily over the years and this trend should continue if only by replacement of older, smaller aircraft. Fuel consumption per seat mile of newer planes, which use more efficient engines, is much lower than for previous models.

The Industrial Market

Chemical and allied products apart, industry will show only a modest growth in energy consumption. The level of industry consumption will also be moderated by industry's improved efficiency in energy use, and this trend is likely to be further stimulated by

CHART 3

INDIVIDUAL MARKET DEMANDS



*CRUDE OIL EQUIVALENT

rising energy costs. Dupont and Alcoa, for example, have already developed plans for achieving significant fuel economies. Shell Oil has committed itself to achieving a 10-percent reduction in energy use in refineries over a period of 2 to 4 years.

Petrochemical feedstock demand will grow very rapidly at an average annual rate of more than 5 percent.

The Residential and Commercial Market

Several factors - particularly population and disposable income - influence the demand for energy of the residential market. It is estimated that this demand will increase from the equivalent of 5 million barrels in 1970 to 6.7 million barrels daily in 1990. Growth in this market is likely to be slower than in the past as the result of better heat insulation in new houses, coupled with the trend toward smaller, mobile, and multiple family dwellings which have reduced requirements for space heating and cooling.

The commercial market includes stores, office buildings, schools, hospitals, and government buildings. Consumption of energy is directly affected by the level of business activity and the demand for public services. It is estimated to increase at more than 5 percent annually and in volume to amount to about 7 million barrels daily by 1990. In both the residential and the commercial markets, gas will be the main supply source throughout the period but electricity will play a growing role.

The Electric Utilities Market

Electricity is a convenient form of energy for customers. It is normally available continuously and automatically, and the precise amount needed is instantly delivered so that the user needs no inventory. Discounting conversion and line losses, it is efficient and it causes the consumer no pollution problems. For these reasons, industry has turned increasingly to electricity with a resulting growth rate annually during the last decade of nearly 8 percent. Looking ahead, between 1970 and 1990, an annual growth rate of 6.4 percent is forecast. The industrial market (including oil and gas companies) is the largest purchaser requiring 41 percent in 1970 and 42 percent in 1990. The residential market which today accounts for almost a third of electricity sales is estimated to fall to 22 percent by 1990 mainly because of energy conservation measures. The commercial market is rapidly increasing its electricity use with the spread of air-conditioned shopping centers, schools, and office buildings, and it is expected to account for 34 percent of total demand by 1990.

Fuel Requirements of Electric Utilities

Energy requirements during the period to 1990 will be met from various sources: nuclear, coal, natural gas, oil, and hydroelectric power.

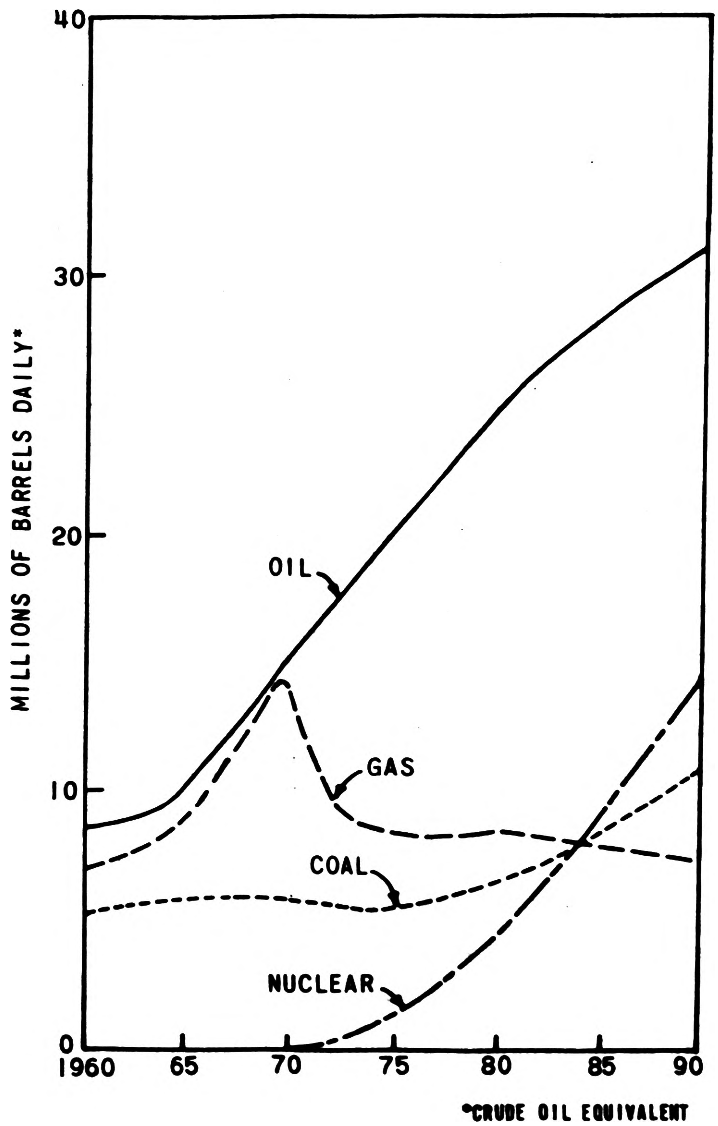
The use of natural gas is forecast to decline because of supply shortage, and hydroelectric power will show only modest growth because of lack of suitable sites. Short-term, oil will replace gas in the fuel supply, and coal will increase its role after stack gas scrubbing is developed fully by 1980. But in the long term, nuclear power will be the fastest growing source of fuel for utilities and will be 58 percent of total supply by 1990.

U.S. Energy Supply

How the United States is expected to meet its energy demand is shown in Chart 4. As the graph shows, oil will be the immediate mainstay of our energy diet, and during the '70's, its contribution to total energy requirements will increase from 44 percent in 1970 to 50 percent by 1980. This increase reflects the projected decline in natural gas supplies and the fact that alternative energy sources will all take a long time to develop. However, domestic reserves of oil and gas are diminishing, and it now appears inevitable that the United States - which now depends on foreign sources for over 25 percent of its petroleum needs - will become considerably more reliant on imports. During the 1970's, for example, most of the growth of the nation's energy requirements (16 million barrels per day) will have to be supplied by imports of foreign oil. By 1990, it is projected that imports will account for about two-thirds of the country's oil needs.

CHART 4

U. S. ENERGY SUPPLY



Oil

Steadily increasing demand, coupled with reduced natural gas supplies, coal's environmental drawbacks, and the delays in nuclear power, have created an energy gap which can only be filled by oil. Demand on supplies is currently about 16 million barrels per day. This is expected to increase by 1990 to nearly 33 million barrels per day.

Domestic production, as shown in Chart 5, will not be able to meet this demand. It is now considered that U.S. crude oil production has peaked at just over 9 million barrels per day and will now decline, even though Arctic crude and production from discoveries in the Lower 48 slow this trend. Production from the Arctic is expected to average about half a million barrels daily in 1977 and is forecast to peak during the late 1980's at 3 million barrels per day. Development of Prudhoe Bay in Alaska along with other discoveries in the Arctic and Lower 48 should help to hold U.S. crude production around the 9 million barrels per day mark during the 1980's.

The dotted lines on Chart 5 indicate the extent to which production would fall were there no additional oil discoveries. There certainly will be new discoveries and the lines show that by 1990, more than half the combined supply from these areas is estimated to come from sources still to be found.

During the period to 1990, oil from shale and coal will make a small contribution of say 1.5 million barrels per day to total energy supplies. An accelerated development program could increase these quantities to perhaps 3 million barrels per day by 1990, but the rate of progress is likely to be limited by pressures on the construction industries and such considerations as water availability, mining labor, and mining equipment.

As shown in Chart 5, the remainder of the U.S. oil supply must come from increasing amounts of foreign sources, including Canadian.

III. PROBLEMS ARISING FROM THE DEMAND/SUPPLY PROJECTION

Provision of Crude Oil

As previously shown, increased energy demand in the next 10 years can only be met by oil supply. To provide by 1980 10 million barrels per day over and above present consumption levels is, by any standards, an immense undertaking. Put graphically, 10 million barrels per day is equivalent to the production of more than five new Alaska Prudhoe Bay fields. To supply oil in this quantity calls not only for the discovery of new fields both at home and overseas, but also for transportation and terminal facilities for the large increase in imported supplies, a massive expansion of refinery capacity, and enormous amounts of capital.

Most of the increase in energy demand will have to be met from foreign sources. The realistic prospect is that a vigorous domestic exploration and production effort will at best only enable the current supply level to plateau instead of decline. To date, the physical problems involved in importing very large volumes of crude oil and products have been given inadequate consideration. Nor has there been much broad public appreciation of the international dimension in which oil supply questions will have to be resolved. For this reason, the import need is dealt with later in the context of the changing pattern of world supplies.

Refinery Capacity Expansion

To process the additional crude oil supplies, a vast expansion of domestic refinery capacity is called for, amounting to some 8 million barrels per day in 1970/80 period. This is equivalent to about 58 average size refineries. Because of environmental problems and capital costs, the industry is likely to make maximum use of the expansion possibilities of existing refineries. This forecast assumes timely and appropriate land use policies and environmental regulations that do not make the construction of new refineries and the expansion of existing plants impossible.

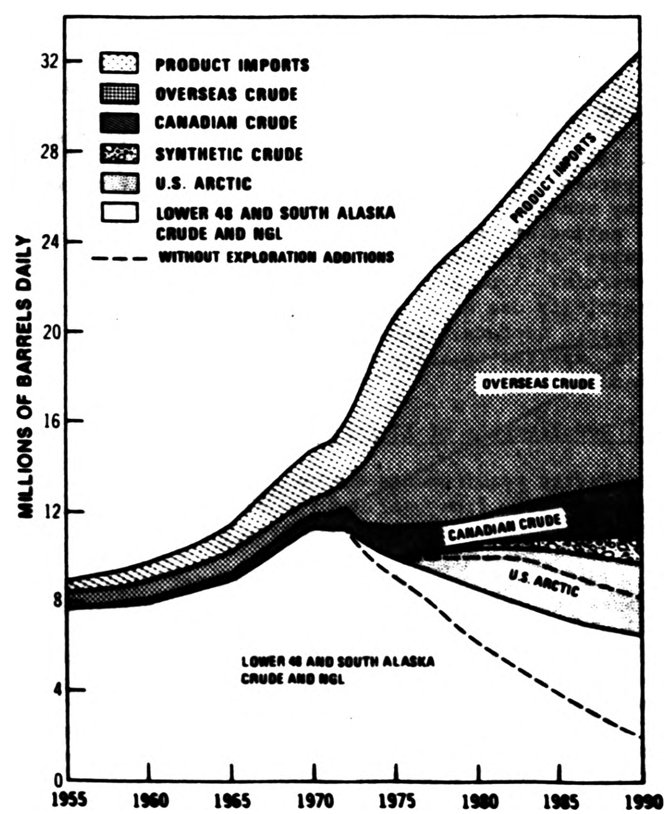
Pipeline Capacity

It appears that by 1980, there will be need for new pipeline capacity beyond present expansion potential both for crude oil and products. This will include product pipeline capacity from the Gulf Coast to the East Coast and crude pipeline capacity from the Gulf Coast to the Midwest.

Shipping and Port Facilities

For its crude and product imports, the U.S. will need by 1980 tanker capacity equivalent to about 325 supertankers, the class of giant transport capable of carrying 1.5 million barrels of oil. This means the arrival daily of six such supertankers, and, since these ships cannot be unloaded in a single day's time, approximately 25 receiving berths will be necessary.

CHART 5
U. S. PETROLEUM SUPPLY



If receiving berths are not available, the alternative is offloading in the Bahamas or Nova Scotia and then reloading on to smaller ships capable of entering U.S. ports. This, of course, means increased cost.

Capital Investment

Provision of these and other necessary facilities will require huge capital investment. During the 1970/1980 period, this is estimated to total over $150 billion.

Cost of U.S. Oil Imports

By 1985, the total annual cost of imported oil could rise to between $30 billion and $70 billion, as shown in Chart 6. These figures are calculated by applying the forecast volume demand against a range of published projections of future oil prices made by responsible experts. Even by 1975, and using crude oil prices that prevailed before the embargo was imposed, expansion of imports will add $8 billion to the import bill.

The seriousness of this dollar outflow is of prime significance in the determination of future U.S. energy policies.

IV. THE INTERNATIONAL DIMENSION U.S. OIL IMPORT NEEDS AND WORLD SUPPLIES

Crude Oil Imports

Our forecast is that U.S. imports of overseas crude oil will increase dramatically from 700 thousand barrels per day in 1970 to 4.3 million barrels per day in 1975. Western Hemisphere sources will be unable to expand their supplies significantly and almost all of this increase will therefore come from Eastern Hemisphere sources in the Middle East and Africa. The significance of Eastern Hemisphere supplies is shown in the following table:

PROJECTED U.S. IMPORTS
(Million Barrels Per Day)

	1970	1980	1990
Total Crude Imports	1.3	11.4	18.3
Overseas Crude Imports	0.7	10.2	16.2
Eastern Hemisphere Imports	0.3	9.2	14.2
Eastern Hemisphere as % Total	23	81	78

Product Imports

Although long term there are clear balance of payments advantages in having import regulations that favor U.S. domestic refining, in the short term there will probably have to be a rapid increase in distillate and residual imports if demand is to be met. The extremely rapid increase in these requirements between now and 1975 will strain the world's refining capability.

The vast expansion foreseen for U.S. oil imports will necessarily have profound effects on worldwide energy supply patterns in the years immediately ahead, and repercussions that are difficult to gauge over a broad range of political and economic matters.

World Energy Demand

World energy consumption is expected to nearly double between 1970 and 1980, increasing from the equivalent of 100 million barrels of crude oil per day to 170 million barrels. By the year 2000, it is projected to increase fourfold, reaching the equivalent of over 400 million barrels daily.

During 1970, the U.S. consumed about one-third of the world's energy. Its share is forecast to decline to 22 percent by 2000, because energy growth rates in Japan, USSR, East Europe, and the developing world are all projected to be higher than in the U.S. over the next 20-30 years.

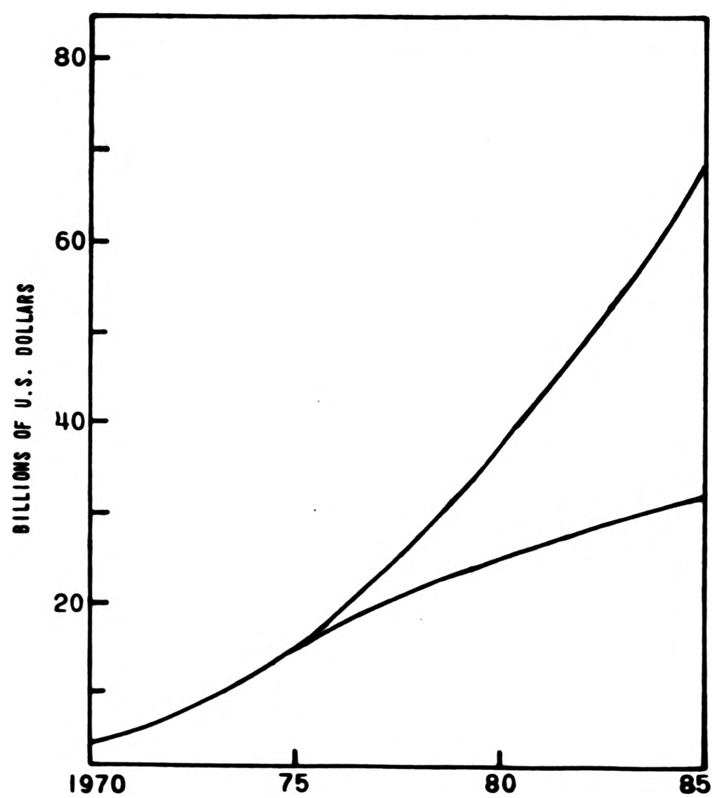
Relative growth rates are shown in the following percentage table:

	1970–1980	1980–1990	% A.A.I. 1970–1990
USA	4.1	3.4	3.8
Western Europe	4.8	5.0	4.9
Japan	7.2	7.2	7.2
Communist Areas	6.5	4.9	5.7
Others	6.8	5.5	6.1
World	5.5	4.8	5.1

Sources of Crude Oil

Chart 7 shows the world's proven reserves of crude oil as of January 1, 1971. The Middle East, with 342 billion barrels of proven reserves, has almost 9 times the reserves of the USA. It is clear that we shall be heavily dependent on the Mid-East for petroleum supplies over the near term. Worldwide oil movements in 1970 and 1980 are shown in Charts 8 and 9. Here, again, the increase in oil movements from the Mid-East is shown to be substantial if the near term demands of the oil-consuming nations are to be met.

CHART 6
RANGE OF COSTS OF U.S. OIL IMPORTS



V. POTENTIAL EFFECT OF ENERGY CONSERVATION MEASURES ON ENERGY DEMAND

In view of the increasing demands for fossil fuels detailed in this forecast and the limited sources of domestic supply, widespread interest in reducing growth in demand is developing. The Federal government has been particularly active in this area, and the so-called Kupperman Report (from the Office of Emergency Preparedness) and reports prepared for the Senate Committee on Interior and Insular Affairs (Senator Henry Jackson, Chairman) are recent results of this activity. We have evaluated potential reductions in demand which might be achieved and conclude that by 1990 a saving of about 7 million barrels per day (crude oil equivalent) is possible relative to the forecast demand. Many of these savings require changes in life style only achievable through an extraordinary national consensus.

Transportation Market

The largest potential (3 million barrels per day of gasoline) could be realized by increasing the proportion of very small cars in the total U.S. automobile fleet. By 1990, we forecast that half the automobile fleet will consist of compacts or subcompacts which will average not much more than 15 miles per gallon. A much smaller vehicle designed primarily for urban use and probably seating only two passengers would be expected to obtain 35 mpg or more. Complete substitution of this smaller vehicle for compact and subcompact automobiles would be possible by 1990 if the energy problem is accepted as being sufficiently severe. The resultant saving in motor gasoline would be 3 million barrels per day if these small vehicles were used for half the total driving.

An additional 450 thousand barrels per day of aircraft turbine fuel could be saved by increasing average load factors from the forecast level of 55 percent to 80 percent. This would undoubtedly cause serious inconvenience to air travelers since many aircraft would be filled to capacity and the interval between flights lengthened.

The combined motor gasoline and turbine fuel savings could be nearly 3.5 million barrels per day.

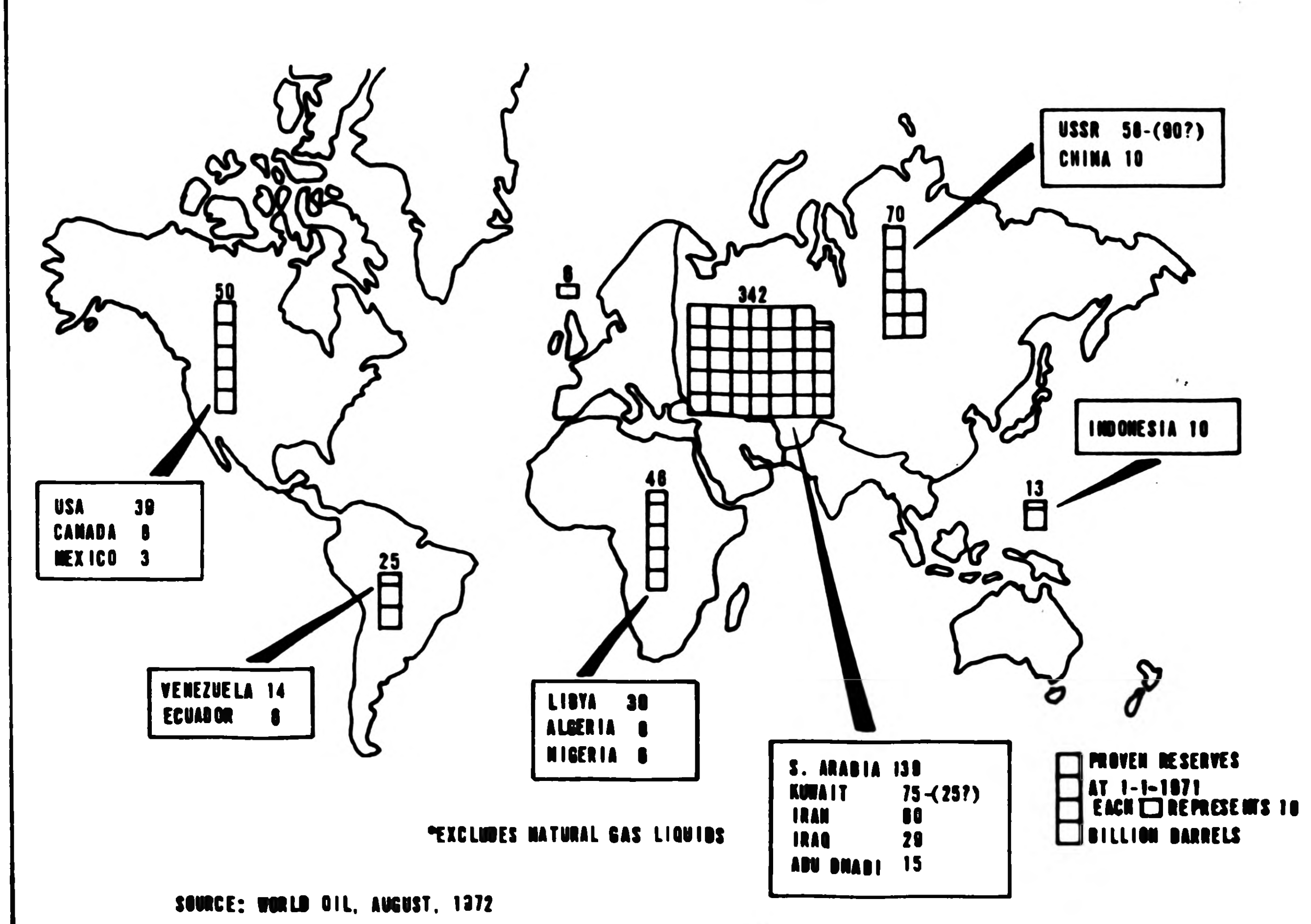
Industrial Market

The next largest potential saving could be in the industrial market. In some industries, such as iron and steel production, the reasonable expectations for increased efficiencies have been included in our base forecast. In others, new technology not now foreseen can be expected to increase efficiency beyond that forecast.

In the chemical process industries (including petroleum refining), however, increased capital expenditures can usually lead to increased heat

CHART 7

WORLD PUBLISHED PROVEN CRUDE OIL RESERVES*



recovery and as fuel prices rise, the incentive to make the capital expenditures increases. A 5 to 10 percent decrease in energy use per unit of output can be expected from increased heat recovery. Use of more energy-efficient processes might contribute somewhat smaller savings. Total savings in the industrial market of 1.5 million barrels per day by 1990 seem possible.

Utility Market

Savings in the utility market could amount to 1 million barrels per day of fuel oil by 1990. Over 80 percent of this potential saving arises from more efficient generation, and of this about half is attributable to more widespread use of currently available high efficiency steam plant design and operation. The balance would require commercialization of new system technology such as MHD (magneto hydrodynamics - a process for more efficient direct conversion of heat energy to electricity) or organic working fluids to use low-level heat presently rejected to cooling water or the atmosphere. A smaller amount could be obtained from more efficient transmission.

Residential/Commercial

Within the residential/commercial market, the largest use of energy is for space heating and cooling. Recent (1971) FHA insulation standards will reduce this demand if widely applied, and our forecast assumes application in 70 percent of new houses. If the balance of new houses were insulated so as to comply with these standards, a saving of 150-200 thousand barrels per day would result by 1990. Application of additional insulation to the presently existing houses could save an additional 300-350 thousand barrels per day for a total potential saving in the residential market of 400-500 thousand barrels per day. Even more stringent standards have been proposed which could save a further 200-300 thousand barrels per day, but these have not been publicly accepted.

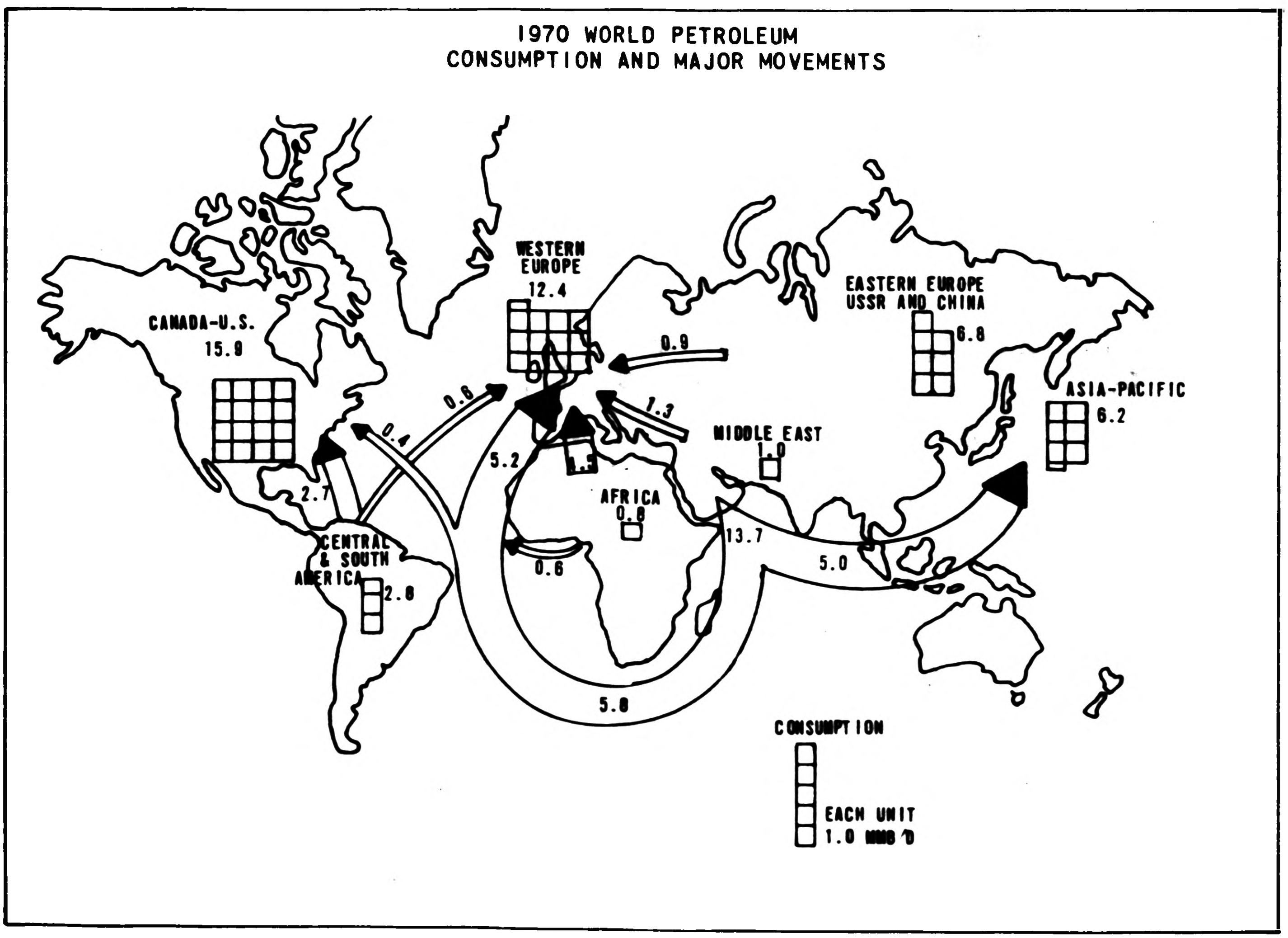
The commercial market (which includes large apartment buildings) could contribute smaller savings estimated at 200 thousand barrels per day. The overall potential saving in the residential/commercial market would be 800,000-1 million barrels per day.

Other Conservation Possibilities

Mass Transit

The development of efficient mass transit is becoming an increasing community priority. Mass transit systems, however, have long lead times and very high capital costs. Hence, the impact on transportation energy demand can, unfortunately, only

CHART 8



be a long-term possibility. The increased use of buses and of car-pooling would similarly have minor impact as only a small percentage of commuters would be affected, but they are worthwhile efforts nevertheless.

Taxation

Increased taxation on automobile horsepower, higher parking charges, and the like could have an impact, but it is considered that such measures would be less effective and acceptable than the use of smaller cars. Moreover, the switch to small cars would not require reduction in miles traveled to achieve energy savings.

Long Industry Lead Times

In considering measures to ease the energy supply situation, the importance of long lead times cannot be overemphasized. In some activities, a sufficient concentration of brains and money can solve problems through "crash" action. In the oil industry, however, as the diagram in Chart 10 shows, planners must think in terms of several years, not months. An understanding of the time factor in oil operations is fundamental.

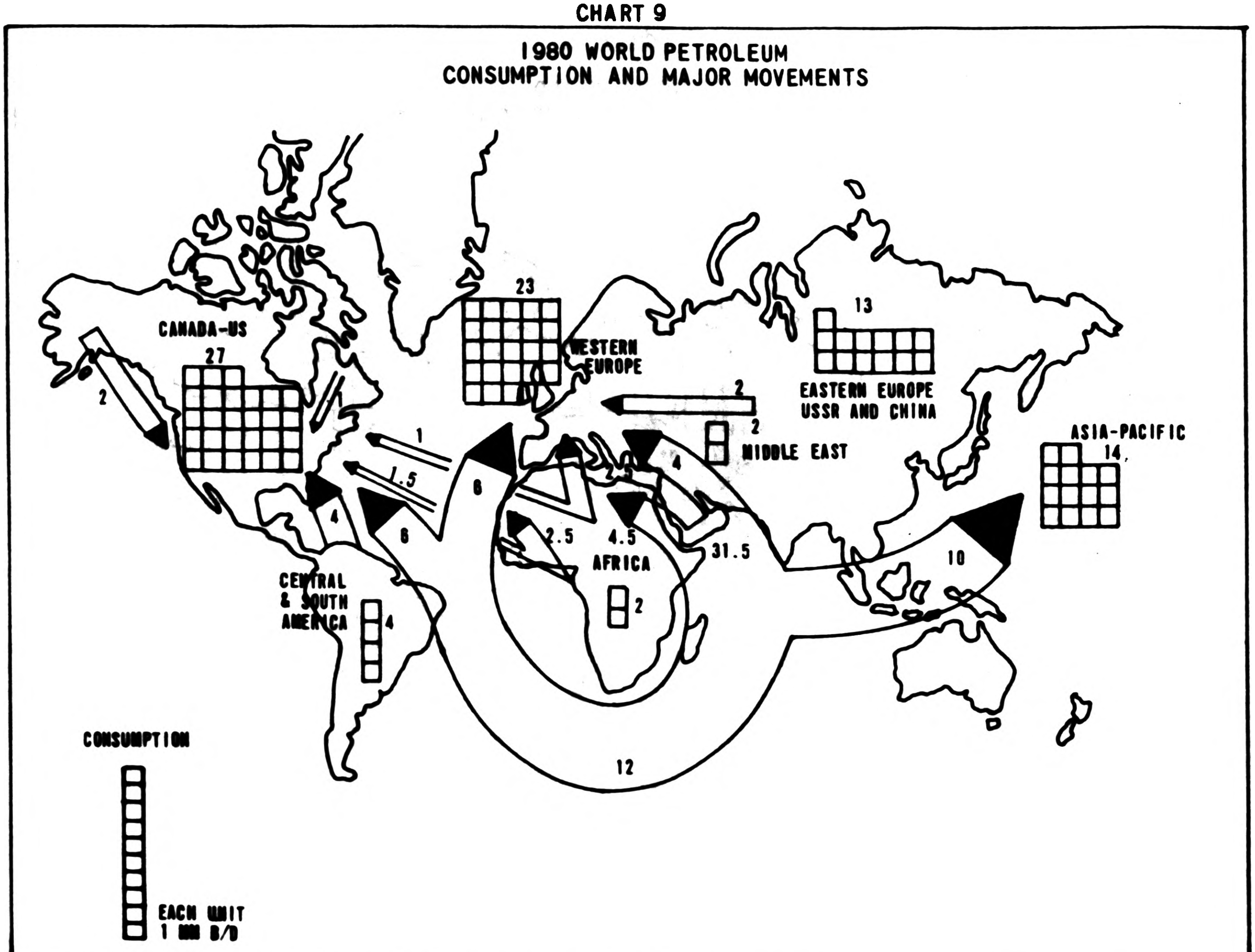
VI. GOVERNMENT MEASURES THAT COULD EASE THE ENERGY SUPPLY SITUATION AND REDUCE DEPENDENCE ON FOREIGN IMPORTS

If the demand/supply forecast outlined in this paper is even approximately correct, it seems clear that a fundamental transition is taking place in the U.S. energy supply position, with sharply increased dependence on foreign oil the key factor.

There is thus pressing need for new national energy policies and some indications of constructive measures that might be taken are given below:

- Speed completion of facilities for supplying petroleum from Alaska.
- Stimulate maximum production of domestic oil and gas.
    - -- deregulate gas prices, thereby allowing prices to reduce demand and thus also provide capital for new exploration work.
    - -- increase the size and frequency of offshore lease sales.

CHART 9



- Nuclear energy development

  -- assist in overcoming siting and environmental obstacles.

- Coal

  -- permit strip mining, given adequate environment and land safeguards.

- Research

  — encourage research on alternative energy sources: solar, nuclear fusion, coal gasification.

- Provide incentives to develop commercial coal gasification and liquefaction.

- Provide incentives to industry to substitute the use of coal for oil and gas in industrial and utility applications.

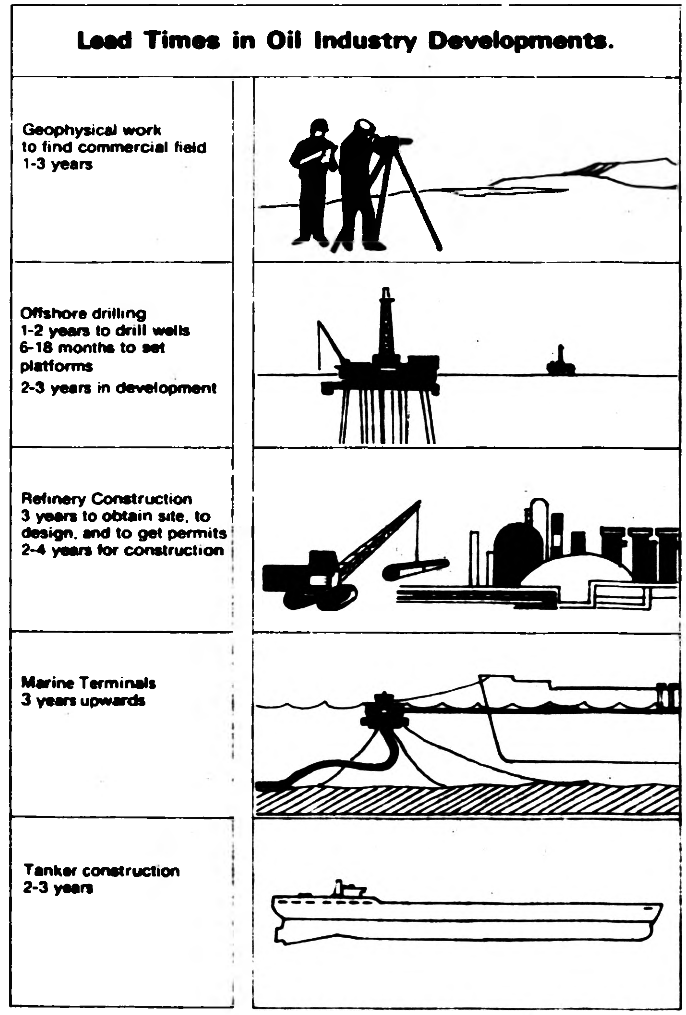
- Assist development of commercial stack gas scrubbing, thus permitting the use of high-sulfur oil and coal.

- Reduce product import requirements by facilitating through land use policies the siting and construction of new refineries and power plants.

- Encourage the construction of new tanker terminals.

The success of an action program such as that outlined above depends on the soundness of the measures proposed, on the adoption of a comprehensive set of policies, and on timely implementation. More than ever, the need is apparent for coordination of priorities at government level, so that conflicting social and economic pressures are resolved in the total context of community needs, and patchwork "solutions" avoided.

CHART 10



THE ROLE OF NATURAL GAS AND LNG IN SUPPLYING OUR ENERGY NEEDS

D. L. Caldwell
J. F. Pritchard & Company
Kansas City, Mo.

ABSTRACT

The domestic natural gas industry experienced a spectacular growth during the two decades from 1950 to 1970. Demand for gas continues to rise and production has peaked at a time when the price for other energy sources is escalating. A price increase can stimulate production over the short term. Massive LNG imports can help the intermediate term supply. The long term natural gas situation is bleak and substitute natural gas sources must be employed. A conservation program and reordering of priorities for energy sources is essential for the United States as well as most industrial nations.

INTRODUCTION

Mr. Chairman and ladies and gentlemen, on behalf of the PRitchard Company I would like to express our appreciation for the opportunity of participating in this conference.

Total Demand for Natural Gas

In 1953, the marketed production of natural gas increased only 5 percent due to mild weather and the sharpest increase in wellhead price since the Bureau of Mines started collecting such data[1]. That is, from 7.8 cents per thousand cubic feet to 9.2 cents! Production was 8 trillion cubic feet. 1953 also marked the start of a project to liquefy natural gas and transport it from Chicago up the Mississippi River via barge and initiate a new LNG transportation industry.

The same Bureau of Mines reference[1] cites \$5.27 per ton f.o.b. for the national average underground coal and \$3.75 per ton f.o.b. average for strip-mined coal. The lower cost of natural gas, less expensive combustion equipment, clean environment, convenience, and other factors created a huge demand for natural gas. The expansion of pipelines and aggressive marketing quickly raised the natural gas share of the energy market from 23 percent to the present 39 percent, and a corresponding production of 22 trillion cubic feet.

A difference of opinion existed between the advocates of low prices for the consumers and the actions of a free market on the value of energy. This led to government regulation of interstate transportation of natural gas and a pricing structure not conducive to continued exploration and development of natural gas fields. The net result, regardless of the details, is that the demand for natural gas exceeds the finite supply, and this trend will continue into the future.

A word on the position of Missouri may be appropriate. Small, non-commercial natural gas fields may be found near the Kansas border, especially near Kansas City. Several large natural gas pipelines traverse the state from the South and West to supply the larger population centers. But Missouri must be included near the lowest quartile of states on the basis of all energy sources available. A high ash-sulfur coal is the principal natural energy resource and may be required for conversion to clean fuel gas and liquids. Fortunately, neighbor states have coal, gas or oil in large quantity. The Missouri and Mississippi Rivers provide barge transportation that can move Montana and Dakota coal and lignite seasonally.

The consumption of energy is directly correlated with the economic status of a region. Conservation must be practiced to avoid waste and to use energy in an efficient manner. Curtailment of energy use because our society might run out of energy would be disastrous. The United States with 6 percent of the world population does consume 35 percent of the energy, but it is also the most productive. Our domestic natural gas production has already peaked. Potential gas supply within the main 48 states is estimated as 780 trillions of cubic feet by the Potential Gas Committee[2]. The cumulative production to December 31, 1972, was 432 trillions. The proved reserves are 235 trillions and have shown a steady decline since 1966. Drilling is more expensive per foot, the expected fields are deeper, venture money is more expensive, the time between a discovery and development is now longer, typically eight years, and the magnitude of financial and engineering problems becomes apparent. The easy gas is already in production or near exhaustion. The shortfall of natural gas is now 20 percent and increasing 5 percent per year. Obviously, we are in trouble.

Southern California Edison Company has been effectively stopped by environmental pressures from building or expanding major generation stations. The nuclear facilities and fossil fuel plants alike have met opposition. Desert stations did not fare any better than the coastal sites. Low-sulfur oil from Indonesia replaced most of the domestic oil and coal. The escalation in foreign oil prices has increased the demand for natural gas at a time when natural gas supply is curtailed.

The essence of the natural gas shortage problem can be seen when electricity from natural gas costs one-half that of oil, even before the recent escalation of Fall 1973. Natural gas as fuel created less opposition from environmentalists, the price was also less, and demand soared. Southern California is therefore one of the prime candidates for massive LNG imports.

Public utilities have in principle been able to pass on increased fuel costs to its customers, but the "regulatory lag" between applications and allowed rate increase devours profits in rapid inflation of alternate fuel costs. Electricity must be generated with demand, and natural gas cannot be stockpiled, as was coal, to assure a supply of fuel. LNG is a partial answer to fuel storage, but the cost of LNG storage is prohibitive compared to fuel oil or coal. We, therefore, may see the advent of hybrid systems, with minimum LNG storage for base load natural gas fired plants, and massive low-sulfur oil storage for stockpiled fuel. The use of natural gas for boilers is admittedly an inferior use of clean natural gas, but the price of LNG imported is now competitive with foreign oil and the existing plants must be fueled until alternative generating systems can be operational. The lead time for nuclear power is now longer than LNG imports.

Demands Vs. Allocation

The most visible demand for natural gas is residential. The housewife is a voter and her usage of approximately 24 percent of natural gas consumption carries an immediate vocal impact upon the government regulatory bodies when the utilities are compelled to curtail energy. A slower but ultimately more powerful force will be the influence of an energy curtailment on agriculture. The relation of food production and the energy supply has shown an ever increasing dependence on nitrogen for our high agricultural output[2]. The energy input for corn production, for example, is higher in the form of nitrogen fertilizer than as of gasoline.

Petrochemical feedstock requires energy as gas, oil or coal in the ratio of 14, 82 and 4 percent, respectively. The natural gas portion, however, represents only 2.3 percent of the total natural gas consumption. This is a small but vital segment since existing steam-reforming plants for the production of hydrogen and ammonia cannot switch to coal, the most abundant energy source. Interruptions to fertilizer production have occured this winter so that the reduced supply of ammonia and nitrogen solutions has increased prices. A normal 6 percent rise in demand may be exceeded in view of prospects for good agriculture prices, and a firm domestic and foreign market.

The priorities of end use must take into account the dislocation of the human food chain if natural gas for petrochemical feedstock is not given a high priority. Who is to be denied the gas? In time, the use of natural gas for process heat, electric power generation and commercial space heating may be decreased by alternative energy. The problem seems to be one of longer range planning than allocation of available supply. The incentive to switch is not now an economic one, but should be. Technology is flexible and will present solutions when the economic rules are known sufficiently in advance. Oil or coal can be used as the starting point for substitute natural gas, ammonia, methanol or a range of heavier hydrocarbons. The chemistry is proven; the hardware stage lags because pilot plant and demonstration plant stages lack the risk capital.

Potential Supply

The supply of natural gas in the United States, including the continental shelves and Alaska, requires definition. Cumulative production is based on records of actual production and are accurate to the limits of measurement and data gathering. Proved recoverable reserves include gas in tested geologic formations that can be produced under existing economic conditions and also include gas in undrilled formations that are so related to developed fields nearby that productive ability is assured. The proved reserves at the end of 1972 was 266 trillions of cubic feet. This figure may be compared with 291,287 and 289 in the preceding two year periods. The United States has peaked in 1972 in proved reserves and also in production, which now stands at 22.5 trillions cubic feet per year.

The ratio of proved reserves to current production is 11.8 years and falling. Obviously, natural gas will not be a museum specimen in this century or even into the middle of the next. The hope lies in the potential natural gas discoveries and may be subdivided into probable, possible and speculative. The probable is 266 trillions cubic feet which, by coincidence, is the same as proved reserves. The possible and speculative supply of 384 and 496 trillions cubic feet, respectively, include offshore, deep drilling over 15,000 feet and Alaska. (The collection of these figures by the Potential Gas Committee is published biennially by the Potential Gas Agency of the Colorado School of Mines.)

The aggregate potential supply of 1146 trillions when combined with the proved reserves of 266 trillions gives a comfortable 62.6 years, based on current consumption. But is this realistic? Energy demand growth was 5.6 percent per year during the 1960s. If by some crash exploration and development program, the increased demand for natural gas can be produced without regard to cost, all U.S. potential gas supplies will be exhausted in 1994. In these terms, we have a crisis.

Natural gas imports, domestic production of substitute natural gas and switching of energy demands to other sources of energy is called for. The other energy sources are also in short supply until a coordinated energy plan materializes. Cost is the lever in a free market system. Some lessening of demand will result from increased cost, but the supply is elastic and will respond to the proper price.

Time must also be factored into the options available. Immediate, short, medium and long range mix of actions is required to buy time for the ultimate solution. We cannot propose nor even suggest what that ultimate solution may be, but some phases of actions are presented as examples.

Immediate Federal Power Commission deregulation of wellhead prices for old or vintage gas is necessary in order to provide the capital to put the first phase in operation. This may not be too severe an option since interstate gas sales, or about 40 percent of gas supplies, are state regulated. Opposition by the consuming states should be overcome if a curtailed supply at low price is compared with adequate supply at some increased price. The distribution companies are price regulated, tax-paying utilities, so there will still be some control on consumer prices. Existing gas contracts must be honored or mutually renegotiated. Two or three months should open capped wells, increase wellhead compression capability, and produce gas in excess of present non-profitable gas contracts.

The second supply phase is gas import from Canada and Alaska. The Canadian lead time can be two to three years from Alberta. Alaska and the Mackenzie Delta gas are five to eight years away from initial delivery. When costs are considered, alternate fuels from coal may just as attractive.

The third supply phase is LNG imported from Algeria, Alaska, Iran, Indonesia, Nigeria, South America and The Soviet Union; not necessarily in that order. The reserves are enormous and the only restraint will be balance-of-payments. Algerian LNG imports can significantly increase from the present projects at Arzew and Skikda in less than five years. The Hassi R'Mel and Rhourde Nuss fields exceed 50 trillion cubic feet and can deliver to existing liquefaction sites. The other countries require a longer lead time before massive LNG delivery can bridge the gap to the next phase.

The fourth supply phase must be coal gasification. We have witnessed an attempt to provide SNG from both the light and heavy hydrocarbon liquids. The technology is available, the feedstock is not. Existing plants will continue to operate but new construction is in limbo. Coal is abundant in the United States and can extend the useful life of the huge existing gas distribution network. Other papers in this conference will cover coal gasification technology.

The fate and timing of the gas supply phases is largely a matter of economics, domestic and international. Some gas producing states do not like to be regulated for the benefit of another gas consuming state. The effect of a balance-of-trade deficit due to massive energy imports of oil or gas does not stop at a state line. The four phases must be dovetailed to continue a supply of energy in convenient gaseous form until an ultimate solution emerges.

LNG Technology and Costs

Natural gas occupies about one six-hundredth of its volume when liquefied at atmospheric pressure. Natural gas to be liquefied must be properly treated to remove carbon dioxide and hydrogen sulfide, if present, and water vapor, as well as aromatic and heavy hydrocarbons likely to freeze. Liquefied natural gas offers features highly desirable for peak shaving high demand of limited duration. Large quantities can be economically pumped to any desired delivery pressure, vaporized and added to the existing gas distribution system with complete interchangeability. The only undesirable feature is the potential hazard of a large volume of flammable liquid.

This hazard has long been recognized. Through pioneer work of the Consolidated Natural Gas System, and its subsidiaries, the Hope Natural Gas Company in West Virginia and the East Ohio Gas Company of Cleveland, the first peak shaving plants were constructed. The lack of available cryogenic steels resulted in failure on one LNG storage, without diking, when a disastrous fire destroyed the Cleveland plant in 1944 after four years of operation. Public reaction to the loss of life delayed acceptance of LNG for more than 15 years.

Pritchard was deeply involved with exhaustive fire and storage studies at Lake Charles, Louisiana, in the late 50s and early 60s to prove LNG storage to be safer than LPG or gasoline. The light molecular weight rapidly disperses vapors with no tendency to form explosive pockets at ground level.

The tragic fire at Staten Island, New York, in a novel LNG storage system while undergoing repairs, is generally considered as an isolated accident not likely to be repeated. It should be noted that no danger existed to the area outside of the tank containment. The conventional storage tank design has a heavy inner tank of aluminum or 9 percent nickel steel with an outer vapor-tight carbon steel tank and insulation between the tanks. Earthen or concrete dikes surround the tank. Very large LNG storage tanks also have been constructed of prestressed concrete.

The sea transport of LNG was successfully demonstrated in seven voyages of the Methane Pioneer from Lake Charles, Louisiana, to Canvey Island, England, and the floating pipeline was born. Pritchard and Technip, in a joint engineer-constructor venture for CAMEL, placed the first base load LNG plant in operation at Arzew, Algeria, in 1964. The LNG produced was destined for England and France and thus initiated international trade. Since then the LNG tankers have increased from 27,400 cubic meters to a "standard" of 125,000 cubic meters, about the limit of a single screw ship. Larger twin-screw ships are under study but not presently on firm order.

The various large exporting sources of excess gas reserves are Algeria, the Persian Gulf area, Nigeria, Indonesia, Alaska, Australia and the world's largest reserves of the U.S.S.R. Importing energy-short nations are Japan, France, England, Italy and the United States. The shortages will grow and competition for this energy will increase in pace with the demand for crude oil and its products. The financing of these projects present major challenges. For example, a plant in the Persian Gulf to export one billion cubic feet per day to the United States, either east, west or gulf coasts, costs about 450 million dollars; the wells and pipeline another 250 million, the 18 LNG transports at over 100 million each and receiving terminals at close to 100 million each - 2.5 billion total. (Same SNG from coal; 1.6 billion including mining.) But this size of plant must be duplicated many (30) times to alleviate the projected short fall of 30 billion cubic feet per day of unsatisfied demand by 1980, the target date of Project Independence. Obviously, the demand cannot be allowed to climb as projected.

The industry faces manpower shortages for engineers, designers and construction specialists as well as material for a large LNG import program. The projects will develop only as fast as the men, material and finances become available.

Current News

Before presenting the conclusions, it is appropriate to mention three news items which nicely illustrate some of the forces at work:

1. A major gas distribution company announces the suspension of construction of a big plant to make SNG from petroleum because suppliers cannot deliver feed stocks in accordance with contracts already ratified.

2. The office of coal research awards a feasibility study of various processes to convert coal to SNG. The estimated completion time for study is two years.

3. Fourteen major oil and gas companies, which have been studying the methanation step in the manufacture of SNG from coal on a commercial scale in Scotland, will now support development on a commercial scale of a process invented by the British Gas Corporation for the gasification of coal. This process was invented more than ten years ago, but has never been taken beyond the pilot plant stage.

Conclusions

The energy shortage is here to stay and LNG imports can furnish but a small portion of the projected shortfall. Natural gas is a vital segment of the energy spectrum and the effort must be made to: (i) reduce demand; (ii) increase domestic production for the immediate demand; (iii) establish a system of priority energy use, preferably based on a free market with a minimum of political regulation; (iv) develop an alternate supply of substitute natural gas from coal; (v) expand LNG peak shaving plants to avoid distribution bottlenecks; (vi) increase import of natural gas from Alaska and Canada; (vii) aggressively develop import LNG programs; and (viii) develop the long range solutions such as nuclear energy.

Acknowledgement

The writer expresses his appreciation to Leonard K. Swenson for his substantial contribution to this paper.

OIL SHALE AND ITS POTENTIAL UTILIZATION

G. U. Dinneen
Laramie Energy Research Center
Bureau of Mines
U. S. Department of the Interior
Laramie, Wyo.

ABSTRACT

The large deposits of oil shale in the Green River Formation in Colorado, Utah, and Wyoming offer a potential source of significant quantities of liquid fuels. This paper discusses the location and potential of the resource; the present state of technology for producing shale oil by both aboveground and in situ processes; the characteristics of shale oil; environmental aspects of oil-shale utilization; and recent developments, particularly results of the Department of the Interior's Prototype Oil Shale Leasing Program, that suggest inauguration of commercial oil-shale processing.

INTRODUCTION

Oil shales of the Green River Formation in Colorado, Utah, and Wyoming comprise one of the largest deposits of hydrocarbons in the world, and are a potential source of significant quantities of liquid fuels. They are sedimentary rocks containing solid organic material that can be decomposed by heat to yield an oil from which the products normally obtained from petroleum can be produced by appropriate refining techniques.

Various attempts have been made since before World War I to develop commercial processes for utilizing Green River oil shale. Most of these have involved mining the shale and processing it in aboveground equipment, but recently in situ processing has received considerable attention. The first approach is reasonably well developed and will probably be used where the shale can be readily mined. The second approach requires more research, but it may have an economic advantage, it may be applicable to deposits of various grades and thicknesses that do not readily lend themselves to mining, and it avoids the problem of disposing of large amounts of spent shale. Both approaches have potential environmental effects that must be taken into consideration.

Although there is no present oil-shale industry in the United States, the current status of oil-shale technology and the country's need for new energy sources suggest that the start of such an industry may be imminent. This paper describes the availability and potential of oil shale, the current technology for producing and utilizing shale oil, the potential environmental effects of oil-shale utilization, and recent developments suggesting commercial development.

LOCATION AND POTENTIAL OF OIL SHALE

Oil shales are widely distributed throughout the United States, but the largest and richest deposit is in the Green River Formation. Hence, most efforts to utilize oil shale have been on material from this formation, and it will be the one considered in this paper. The formation, whose location is shown in Figure 1, covers an area of about 17,000 square miles in four principal basins: The Piceance Creek Basin of Colorado, the Unita Basin of Utah, and the Washakie and Green River Basins of Wyoming. In this formation, oil-shale intervals that are at least 10 feet thick and that yield at least 25 gallons of oil per ton have a potential oil yield in place of 600 billion barrels as shown in Table 1.[1] If thinner shale as lean as 10 gallons per ton is considered, the potential oil yield is increased to some 2 trillion barrels.

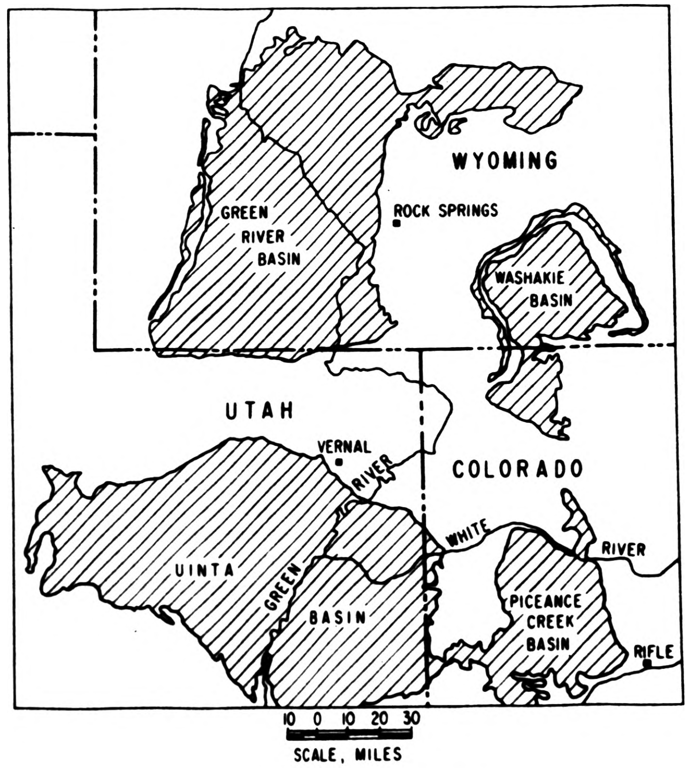


Fig. 1. Three state map.

I. POTENTIAL SHALE OIL IN KNOWN DEPOSITS OF THE GREEN RIVER FORMATION

	Billions of Barrels of Oil in Place			
	Colorado	Utah	Wyoming	Total
Intervals 10 or more feet thick averaging 25 or more gallons of oil per ton	480	90	30	600
Intervals 10 or more feet thick averaging 10 to 25 gallons of oil per ton	800	230	400	1,430
Intervals 10 or more feet thick averaging 10 or more gallons of oil per ton	1,280	320	430	2,030

Although the Piceance Creek Basin, as shown in Figure 1, contains only a small part (about 10 percent) of the area covered by the Green River Formation, it contains about 80 percent of the richer oil shale (Table 1). The oil shale crops out in cliffs, Figure 2, along the southern edge of this basin. The Mahogany zone, which is the best known interval of the Green River Formation, is about 75 feet thick in the lower part of the cliff just above the talus slope. The rich oil shale thickens toward the center of the Piceance Creek Basin so that in some places continuous sections of oil shale averaging more than 25 gallons of oil per ton are hundreds of feet thick.[2] However, these are generally under several hundred feet of overburden and therefore may not be as readily mined as the outcrops which have received most attention in the past. In Utah and Wyoming the sections of rich shale are not as thick as those in Colorado, and in Wyoming they are often interspersed with alternating beds of lean shale. Hence, somewhat different recovery techniques may be required for these shales than for those in the Piceance Creek Basin.

A major problem in utilization of oil shale is the necessity for handling large amounts of rock that contain only moderate amounts of organic material as indicated in Table II. Fortunately, the organic matter is fairly high in hydrogen so about two-thirds of it can be converted to oil by heating. Unfortunately, it has a rather high content of nitrogen which appears in the oil and must be removed by special techniques before the oil is a desirable refinery feedstock.

Fig. 2. View of cliff.

II. COMPOSITION OF MAHOGANY ZONE SHALE OF COLORADO AND UTAH

	Weight Percent
Mineral matter:	
Content of raw shale	86.2
Estimated mineral constituents:	
Carbonates, principally dolomite	50
Feldspars	19
Illite	15
Quartz	10
Analcite and others	5
Pyrite	1
Total	100
Organic matter:	
Content of raw shale	13.8
Ultimate composition:	
Carbon	80.5
Hydrogen	10.3
Nitrogen	2.4
Sulfur	1.0
Oxygen	5.8
Total	100

TECHNOLOGY

Shale oil may be recovered from the Green River Formation by two general approaches. The first is mining, crushing, and aboveground retorting; this approach has been used in various parts of the world for over 100 years for the commercial production of shale oil and has been studied in this country for many years. It will probably

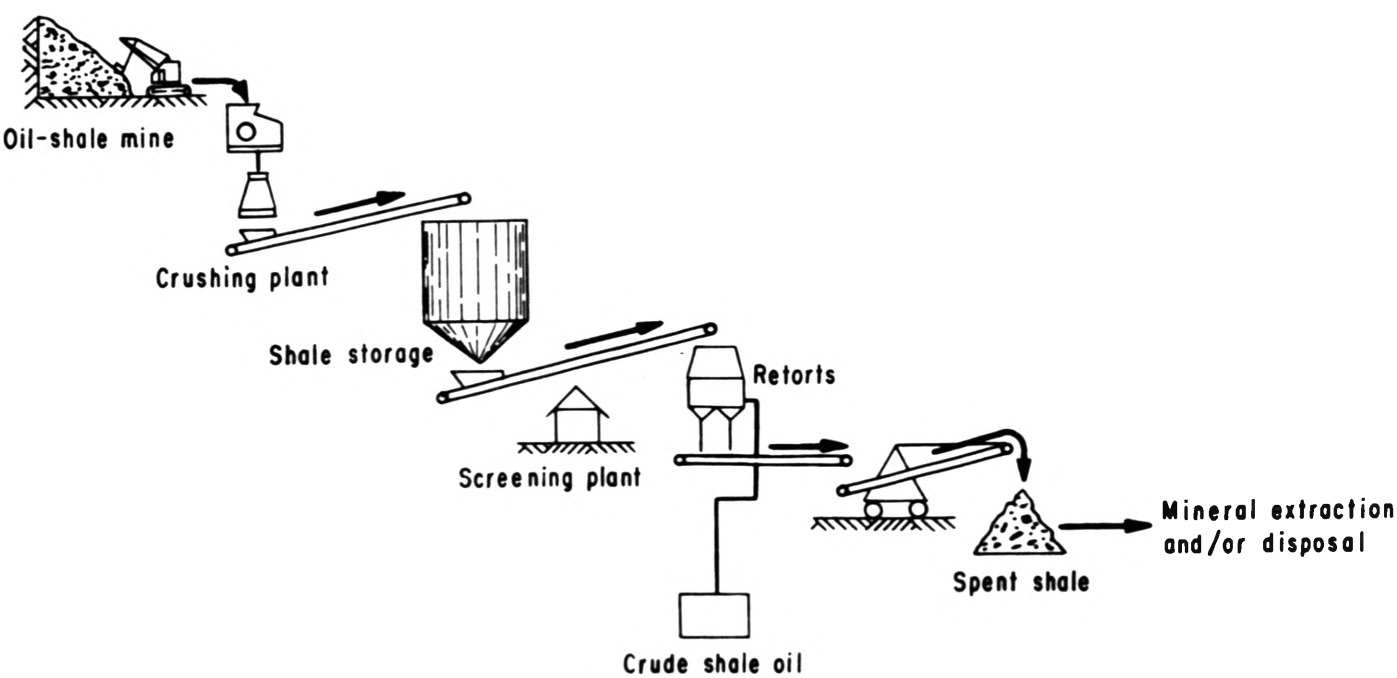


Fig. 3. Schematic diagram of oil shale surface processing.

be used for initial development of the Green River Formation. The second is in situ processing, which has received serious consideration only in the last few years but which has potential economic and other advantages that make efforts to develop a feasible method worthwhile. It might be used where the shale is deeply buried, where it occurs in relatively thin intervals, where it consists of alternating intervals of rich and lean shale, or where various other circumstances exist so that mining cannot be readily applied.* In addition the technique has the advantage of leaving the mineral residues in place, thus eliminating the disposal problem associated with the aboveground approach. However, it may introduce environmental effects of its own, such as adding soluble materials to groundwaters.

Mining and Aboveground Processing

Many attempts have been made to mine and retort Green River oil shale. A simplified schematic representation of this approach is shown in Figure 3. So far all attempts have been on a pilot-plant scale, and no prototype commercial unit has been operated. Five of the more extensive investigations that have been conducted or are being conducted are those by (1) the Bureau of Mines, (2) a group of six oil companies utilizing Bureau of Mines facilities, (3) the Paraho Development Corporation, (4) Union Oil Company of California, and (5) the Colony Development Operation.

Investigations of mining and retorting oil shale and of refining shale oil were conducted by the Bureau of Mines near Rifle, Colo. from 1944 to 1956. A demonstration mine was opened in a 73-foot minable section of the Mahogany zone, and it was shown with fair assurance that low mining costs and high recovery in the room-and-pillar operation were possible.[3] Refining research provided assurance that petroleum refining technology would be adaptable to shale oil.

During the Bureau's program, retorting research led to development of the gas combustion retort[4] which was considered the most promising of the retorting methods investigated. This retort, which is shown schematically in Figure 4, is a vertical, refractory-lined vessel

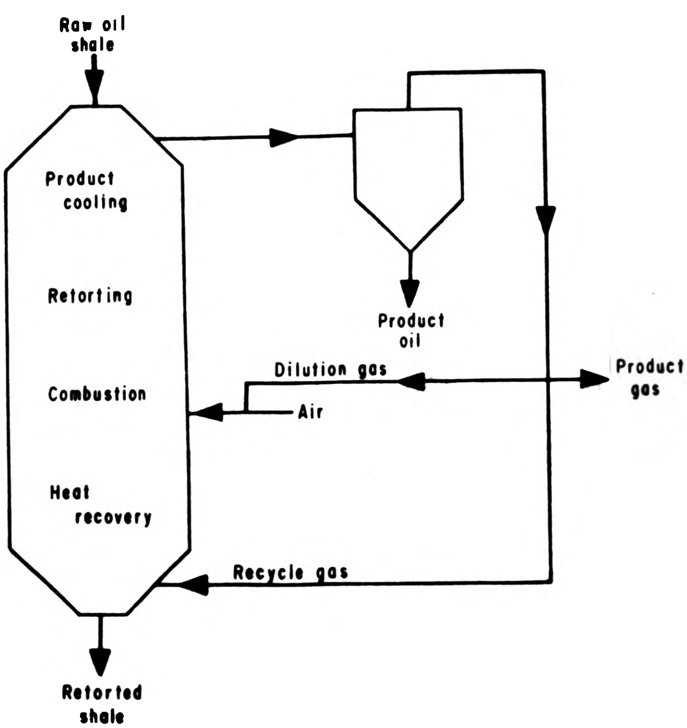


Fig. 4. Gas combustion retort.

through which crushed shale moves downward by gravity. Recycled gases enter the bottom of the retort and are heated by the hot retorted shale as they pass upward through the vessel. Air is injected into the retort at a point approximately one-third of the way up from the bottom and is mixed with the rising hot recycled gases. Combustion of the gases and some residual carbonaceous material from the spent shale heats the raw shale immediately above the combustion zone to retorting temperature. Oil vapors and gases are cooled by the incoming shale and leave the top of the retort as a mist. The manner in which retorting, combustion, heat exchange, and product recovery are carried out gives high retorting and thermal efficiencies. The process does not require cooling water, an important feature because of the semiarid regions in which the shale deposits occur. The development program utilized pilot plants having capacities of 6, 25, and 150 tons per day, but was terminated before operability of the largest of these had been completely demonstrated. However, the process appeared to offer the possibility of large-scale operation.

The gas combustion retorting system was further developed during the period 1964 to 1968 when the Colorado School of Mines Research Foundation leased the Bureau of Mines Rifle facilities and operated them under a research contract with six oil companies: Mobil, which acted as Project Manager, Humble, Phillips, Sinclair, Pan American, and Continental. The research was conducted in two stages, each of which lasted approximately 2 years. The first stage was devoted primarily to investigating the gas combustion retorting process itself in the two smaller pilot plants that had been constructed by the Bureau.[5] The second stage included research on both mining and retorting. The mining involved development of a room-and-pillar method similar to that of the Bureau of Mines except that somewhat smaller pillars were used. It was demonstrated during this stage that the largest gas combustion pilot plant could be operated using feed rates of 500 pounds per hour per square foot of cross-sectional bed area, about double the rate previously achieved by the Bureau of Mines, while maintaining oil yields in excess of 85 percent of Fischer assay. Although the results indicated a significant advance in development of the process, some operating problems were not fully resolved.[6]

A modified version of the gas combustion retorting system, designated as the Paraho retort and successfully applied to calcining limestone, is presently being tested on oil shale in a program supported by 17 companies.[7] Major modifications to the process involve the charging and discharging mechanisms for the retort and the gas injection and process control systems. The test program which started late in 1973 is scheduled to last 30 months and will cost $7.5 million. Two retorts, a pilot plant 2-½ feet in diameter and a semiworks plant 8-½ feet in diameter, will be constructed at the Bureau of Mines Rifle facilities, which have been leased by the Paraho group for their test program.

A retorting system developed by Union Oil Company of California also consists of a vertical, refractory-lined vessel. However, it operates on a downward gas flow principle and the shale is moved upward by a charging mechanism usually referred to as a rock pump. Heat is supplied by combustion of the carbonaceous residue remaining on the retorted shale and is transferred to the oil shale, as in the gas combusiton retort, by direct gas-to-solids exchange. The oil is condensed on the cool incoming shale and flows over it to an outlet in the bottom of the retort. This process also has the advantage of not requiring cooling water. The system was tested during 1956 and 1958 on a demonstration scale of about 1,000 tons per day. It was subsequently announced that operation of the plant had yielded enough information so that the process could be commercialized whenever energy demand and economic conditions warranted.[8] Several recent announcements in the press have indicated that Union may start construction of a commercial plant relatively soon, but the announcements did not give details of the processing scheme that will be used.

The process that appears to be nearest to commercial utilization is the TOSCO II system which is based on a rotary kiln utilizing ceramic pellets heated in external equipment to accomplish retorting. Shale feed ground to less than ½ inch in size is preheated by flue gases from the pellet heating furnace and introduced into the kiln with pellets heated to 1,200° F. In the kiln, it is brought to a retorting temperature of 900° F by heat exchange with the pellets. Passage of the kiln discharge over a trommel screen permits recovery of the pellets from the fine shale for reheating and recycling. Oil vapors are recovered, and the spent shale is routed to disposal.

The TOSCO II process together with a room-and-pillar mining method has been under investigation for several years in a semiworks plant having a capacity of about 1,000 tons per day. The Colony Development Operation—originally composed of the Standard Oil Company of Ohio, The Oil Shale Corporation, and Cleveland-Cliffs Iron Company, but subsequently including Atlantic Richfield Company as Project Manager—conducted this investigation which terminated in April 1972. During the investigation a considerable research effort was also expended on environmental aspects of oil-shale operations particularly in regard to stabilizing and vegetating spent-shale deposits. After the pilot plant was shut down, results were evaluated and design of a commercial plant having a capacity of about 50,000 barrels of oil per day was started. The engineering design for this plant will be completed later this year, and it has been announced that plant construction could start in about October if other phases of the project, such as obtaining a permit for a pipeline from the shale plant location to the Four Corners area, can be completed by that time.[7]

In Situ Retorting

Retorting oil shale in place has been receiving increased attention in recent years because it may have a number of advantages: It may be more economical than the traditional approach; it may be applicable to deposits of various thicknesses, grades, and amounts of overburden that are not readily amenable to mining; and it eliminates the necessity of disposing of large quantities of spent shale. However, it may introduce other environmental problems such as the possibility of groundwater leaching the soluble retorting products left underground. In spite of its potential advantages and recent interest in it, only a relatively small amount of research has been done on in situ processing; consequently, technology is generally in the early stages of development.

In situ retorting might be accomplished by passing gases and liquids either horizontally or vertically through fractured shale. The horizontal approach is illustrated schematically in Figure 5. One application of this approach consists of drilling a predetermined pattern of wells into the oil-shale formation, creating permeability among the wells if naturally occurring permeability is low, igniting the shale in one or more of the wells, pumping compressed air down the ignition well to support combustion of some of the oil shale, forcing the hot combustion gases through the oil shale to convert the solid organic matter in it to oil, and recovering the oil thus generated from other wells in the pattern.

An early investigation of this concept was made by Sinclair Oil and Gas Company, now a part of Atlantic Richfield Company, which conducted experiments in 1953 and 1954 at a site near the southern edge of the Piceance Creek Basin.[9] The results of these experiments indicated that communication between wells could be established through induced or natural fracture systems, that wells could be ignited successfully although high pressures were required to maintain injection rates during the heating period, and that combustion could be established and maintained in the shale bed. Additional experiments were made some years later at a depth of about 1,200 feet in the north central part of the Piceance Creek Basin. These latter tests were only partially successful, at least in part because of an inability to obtain the required surface area for heat transfer.[10]

A modification of the concept shown in Figure 5 was studied by Equity Oil Company of Salt Lake City.[11] The modification consisted of injecting hot natural gas into the shale bed rather than

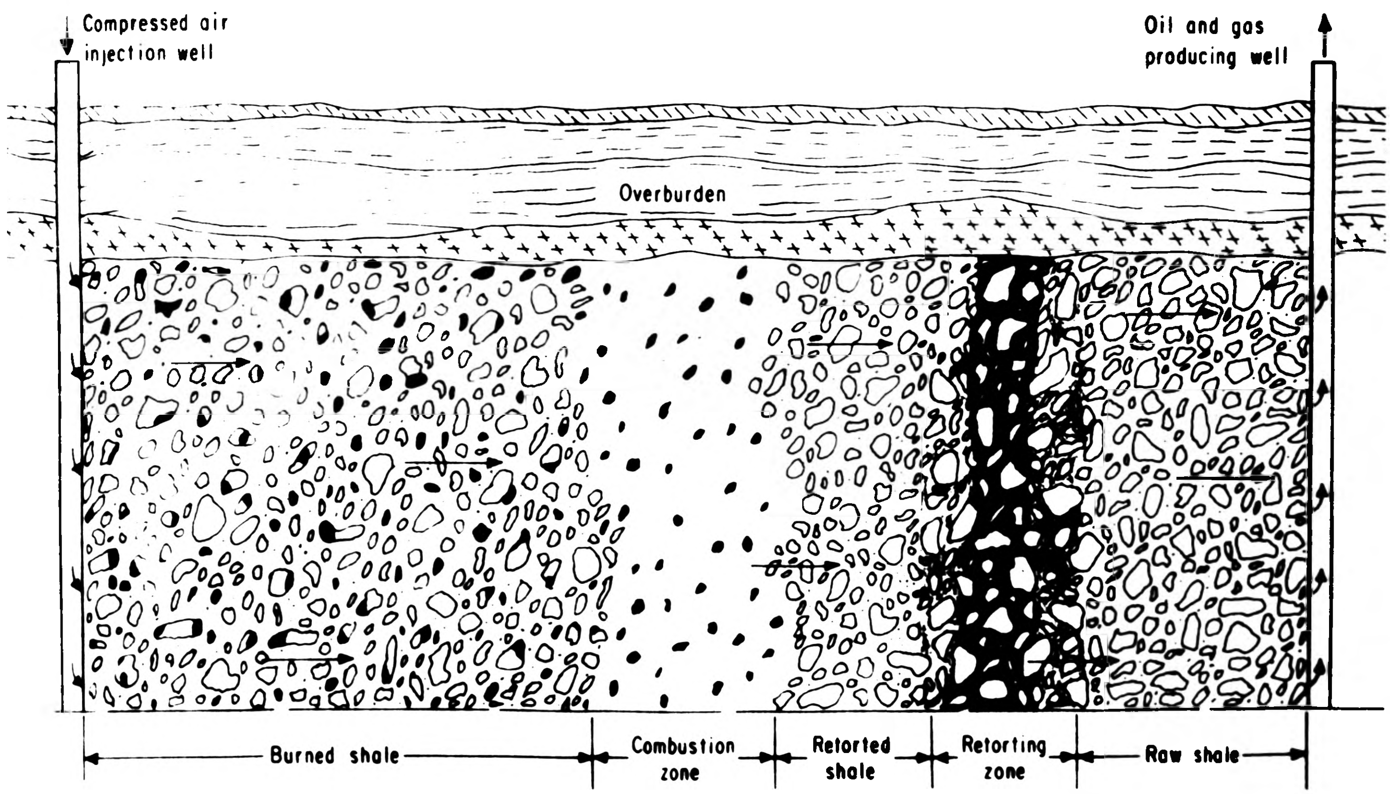


Fig. 5. Schematic diagram of an in situ oil shale retorting process

having an underground combustion zone. A five-spot pattern of one injection well and four producing wells was used in an area of the Piceance Creek Basin having naturally occurring permeability and porosity due to the leaching of soluble salts. Based on results of the experiment and a mathematical model developed from them, it appeared that the technique was feasible and potentially an economic method for recovering shale oil. However, the economics are strongly influenced by the cost of natural gas and the amount required for makeup.

The only field experiment presently in progress utilizing the concept in Figure 5 is being conducted by the Bureau of Mines at a site in southwestern Wyoming between the towns of Rock Springs and Green River. In this area an oil-shale interval about 20 feet thick and yielding from 20 to 25 gallons of oil per ton is relatively shallow–50 to 400 feet deep. Over a period of several years, 10 experiments concerned with various fracturing and recovery methods have been conducted at the site.[12,13] In the 11th experiment, which is presently in progress, three hydraulic fractures approximately 10 feet apart have been created. It is planned to detonate a slurried or liquid chemical explosive in these fractures to break up the shale preparatory to an underground combustion experiment for the recovery of shale oil. It is hoped to start this last phase of the experiment next summer or fall.

An in situ experiment where the broken shale is retorted vertically rather than horizontally is being conducted by Garrett Research and Development Co., on the southwestern edge of the Piceance Creek Basin. In this technique, sufficient shale is mined from the lower part of a room to provide the desired porosity when the shale above the mined portion is fractured by explosives and collapsed into it.[14] The broken shale in the room is then ignited on the top, and a combustion zone is forced down through it by supplying air to the top of the room. The hot gases ahead of the combustion zone retort the shale, and products are removed from the bottom of the room. One such room holding several thousand tons of broken shale was prepared and retorted during 1973 with apparently very satisfactory results. However, a commercial–scale application of this technique will presumably require rooms several times the size of the one completed last year and some additional development work.

A nuclear explosive, rather than partial mining, could be used to prepare a cavity filled with broken shale for in situ retorting. The concept has been discussed since the late 1950's, and a number of detailed plans for a field test have been developed–the latest in September 1973.[15] However, no field test of this technique is presently scheduled.

To furnish appropriate data for improving in situ techniques, the Bureau of Mines conducts both laboratory studies and pilot scale simulation of underground operations. The laboratory studies are concerned with the effects of variables such as the reaction of oxygen with oil shale at subretorting temperatures, the mechanisms of formation and transport of oil out of oil-shale particles, and the effects of pressure on the retorting process. For the simulation studies, two vessels, one with a capacity of 10 tons and the other with a capacity of 150 tons, are used to study such variables as the rate of combustion front travel, gas flows through broken shale, grade of shale, and particle size distribution. The larger of the two pilot plants is shown in Figure 6, which also shows in the left foreground the type of random-sized oil shale used for some experiments. This material ranges in size from sand like particles to pieces weighing a ton or more. For an experiment, the retort is filled and retorting is started by igniting the shale at the top with a natural gas burner. After the burner is turned off, combustion is maintained by injecting air and recycle gas, if used, into the top of the retort. The combustion zone travels down through the bed, retorting the oil shale ahead of it. A tank mounted on load cells is used to collect the

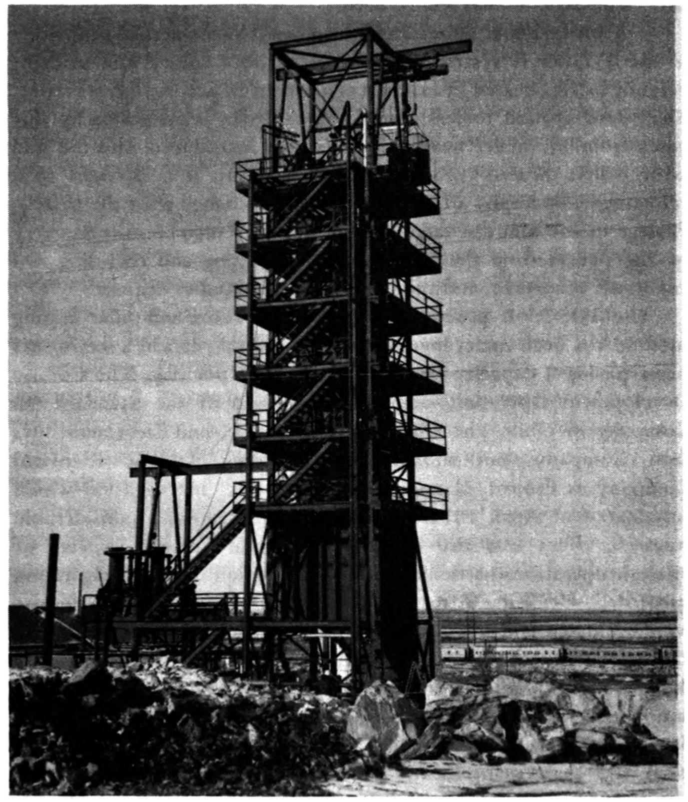


Fig. 6. 150–Ton retort.

liquid products so that a continuous record of retort output can be maintained. Gaseous products from the retort, which contain some oil and water, are passed through packed towers to remove most of the entrained materials. After passing through a blower, some of the gas stream may be recycled back into the retort while the remainder vents through a stack equipped with a natural gas burner to oxidize combustible components. In a number of experiments run in this manner to evaluate the effects of retorting gas velocity and composition, yields up to 65 percent of Fischer assay have been obtained.[16] These are thought to be promising considering the wide range in size of material being retorted and the heat losses inherent in the equipment used.

Oil-Shale Products

The fuels and chemicals normally produced from petroleum can also be obtained from shale oil. However, an adaptation of petroleum technology based on the properties peculiar to shale oil is required. Shale oil produced by some surface retorts, such as the gas combustion retort, is usually a dark viscous material with a relatively low sulfur content but a high pour point and a high nitrogen content (Table III). A high pour point requires that the oil receive some

III. PROPERTIES OF CRUDE SHALE OILS

Retort	Specific Gravity, 60/60°F	Pour Point, °F	Viscosity, 100°F SUS	Nitrogen, wt pct	Sulfur, wt pct
Gas combustion	0.937	80	543	2.16	0.60
10–ton	.923	60	112	1.57	.79
150–ton	.909	60	98	1.59	.94
In situ	.885	40	78	1.36	.72

pretreatment before the oil is amenable to pipeline transportation. The high nitrogen content complicates the refining of the oil, so it appears that hydrotreating of the oil or some of its fractions will be required to lower the nitrogen content to acceptable levels for processing by refining methods such as catalytic cracking. In situ processing and some surface retorting systems may yield oils with low enough pour points to materially ease the problems of handling.

Environmental Considerations

Environmental effects directly associated with oil-shale processing are expected to be from retorted or burned shales, waters that have been produced or used in processing, and gases. The present interest in in situ processing is partly because this technique would obviate the necessity of disposing of large quantities of retorted or burned shale. However, one factor in proving in situ processing to be feasible is the necessity to determine what effect leaching of the in place retorted shale and produced waters will have on groundwater. A start toward investigating this problem has been made by the Bureau of Mines at its Rock Springs field site where a program of well drilling and water sampling is in progress.

Although in situ processing offers some potential advantages, many portions of the Green River deposit appear to be most amenable to mining and aboveground processing as means for recovering shale oil. Hence, industry and government are both investigating problems associated with disposal of retorted or burned shale. In particular, the Colony Development Operation has done a substantial amount of work on the vegetation of retorted shale from the TOSCO II process and has shown that this can be accomplished. In another study, Colorado State University in a program sponsored by industry and government, both State and Federal, established spent shale test plots at two elevations in the Piceance Creek Basin during 1973. These plots are designed to establish the requirements for germination of selected plant species and the survival rate under natural conditions.

Retorting oil shale produces water both from heating the shale and from burning the fuel when the process uses internal combustion. This water will generally be in the range of 3 to 10 gallons per ton of shale retorted. Because it has been in contact with shale oil, it contains substantial amounts of organic material in addition to inorganic ions from the minerals in the shale. Some studies of this water and suggestions for its treatment have been made,[17] but additional ones will be required as more specific plans for utilization of oil shale are developed.

Gases from oil-shale processing are not expected to have a unique composition, so gas treating methods being developed by other industries to comply with environmental requirements should be applicable to oil-shale gases. However, to confirm this postulation gases from pilot plant developments, such as those being conducted by the Bureau of Mines, should be sampled and analyzed.

In addition to the direct effects of oil-shale processing on the environment, there will be other effects from the development of an industry, particularly from the accompanying influx of people to a semiarid, sparsely populated area.[18]

RECENT DEVELOPMENTS POINTING TO COMMERCIAL UTILIZATION

Because the oil-shale deposits are about 20 percent privately owned and about 80 percent government controlled, there is an opportunity for development on both types of land. However, since the government-controlled lands were withdrawn from leasing by President Hoover in 1930, there has been no procedure to provide for industrial development on them. In an effort to overcome this, the Department of the Interior developed over the past several years a prototype leasing program which resulted in offering two leases in each of the three states–Colorado, Utah, and Wyoming–where the Green River Formation occurs. These leases, each of which is a little over 5,000 acres in size, are being offered on a monthly basis starting with the first bid opening on January 8, 1974. The successful bidder on the first tract, which is in Colorado, was a combination of Standard Oil Company (Indiana) and Gulf Oil Corporation, with a bonus bid of a little over $210 million. The second tract, also in Colorado, went to a combination of Atlantic Richfield Company, Ashland Oil Company, Shell Oil Company, and The Oil Shale Corporation for a bonus of over $117 million. The third tract, which is in Utah, went to a combination of Phillips Petroleum Company and Sun Oil Company for a bonus bid of over $75 million. The size of these bids seems to indicate a genuine intention to develop the leases in the foreseeable future. However, this will of course depend on the future energy situation which is presently difficult to predict.

There have been two recent announcements indicating some intention to proceed with development on privately held land. The Colony Development Operation has applied for a number of the permits that will be required in order to start construction of a plant when engineering design is completed in the fall of this year. Union Oil Company of California has announced its intention to start construction of a plant in the foreseeable future.

SUMMARY

Green River oil shale in the States of Colorado, Utah, and Wyoming has the potential of supplying significant quantities of fuel to help fulfill the nation's needs. Past attempts to utilize the oil shale have generally involved mining, crushing, and retorting shale aboveground. It appears that this approach will probably be applied successfully in the foreseeable future. In addition, attention is presently being given to developing in situ techniques which may have advantages, particularly from an environmental standpoint. One technique has been operated successfully in a field test and should be ready shortly for commerical-scale demonstration. The range of fuels and chemicals presently produced from petroleum can be otained from shale oil if techniques appropriate to its particular composition are used. Bids recently made on leases of oil-shale land offered by the Department of the Interior and announcements made by companies holding private land both suggest that commercial development of oil shale is imminent.

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COAL AND ITS DERIVATIVES AS AN ENERGY RESOURCE

By: W. G Stockton
Vice President, Public Relations & Traffic
Peabody Coal Company

Chemical Energy Session
UMR-MEC Conference on Energy Resources
Rolla, Missouri

April 25, 1974

Events of the last few months, it seems, have somewhat altered the public countenance of the coal industry. These events, I am sure, are the generating factors focusing interest on our industry currently, and I suspect they account for my invitation to address this distinguished group of engineering students today on the subject of coal in this nation's energy outlook.

Coal Mining is not a new industry - - it has been around a long, long time. A surprising number of people, though, have never seen any coal; they are not aware of the existence of the industry, or its relationship to the overall energy picture of the United States.

I have assumed that most of you are concerned about the energy crisis as it touches you, personally, but I hope your interest is broader than that. Many people have asked the question, "If the energy crisis is for real, why didn't someone warn us?" Well, if you are like most other people, you don't read everything in the newspapers or in the several weekly news magazines. All of us are inclined to pass over those items and articles that don't directly affect us in our daily lives. I can tell you that the warnings have been there, publicly stated, printed and reprinted. Let me show you what I mean:

1952

"In area after area we encounter soaring demands, shrinking resources, the constant pressure toward rising real costs, the strong possibility of an arrest or decline in the standard of living we cherish and hope to share. As a Nation, we are threatened, but not alert . . ."

PALEY COMMISSION REPORT
June, 1952

1954

"With demand increasing and the rate of discovery decreasing, after a time a definite shortage of gas occurs . . . the net result to the consumer is a shortage of supply and an increase in rates."

HINES H. BAKER
President, Humble Oil and Refining Company
December 1, 1954

1957

"Legislation freeing gas producers from public utility type regulation is essential if the incentives to find and develop new supplies of gas are to be preserved and sales of gas to interstate markets are not to be discouraged to the detriment of both consumers and producers, as well as the national interest."

President Eisenhower's
Budget Message to Congress
January 16, 1957

1960

"I can safely predict that between now and 1975 we will have an energy crisis in this country. Then the people will say 'The industry is to blame, why weren't we told?' Well, I'm telling them now."

MICHEL T. HALBOUTY
Houston Consulting Geologist
September 3, 1960

1963

"Today in the United States there is only a 20-year known reserve of crude oil and natural gas . . . if we stopped production for a period of just weeks there would be a shortage."

RAYMOND PLANK
President, Apache Corporation
January 11, 1963

1965

"The ratio of proved reserves to demand for both oil and gas continues to decline, in the face of steadily rising demands. Adequate prices are essential incentive to encourage greater search for new oil and gas reserves."

Phillips Petroleum Company
Annual Report, 1964
March 18, 1965

1966

"The days of world crude-oil surplus are coming to an end."

ROBERT O. ANDERSON
Chairman, Atlantic Richfield
August 1, 1966

1967

"As a consequence of insufficient incentive, domestic production adequate to meet consumption requirements in the years ahead is unlikely."

ROBERT G. DUNLOP
President, Sun Oil Co. and
Chairman, American Petroleum Institute
October 30, 1967

1968

"It's been a year now since the Arab and Israeli armies fought their brief war. This anniversary offers a good chance to point out the lesson these experiences taught. The troubles proved again that heavy reliance on foreign oil is a most insecure base for this nation's energy needs."

Oil and Gas Journal Editorial
June 10, 1968

1969

"Adverse tax changes would have on one result: aggravation and intensi cation of the already critical supp situation as to U.S. supplies of na. ral gas."

H. A. TRU
Independent Producer, t
before the Senate Finance Comm
October 1,

1970

"We are rapidly passing from a ph of energy abundance to one of e ergy scarcity. The gap between d mestic supply and demand is no widening so rapidly that not even t indicated production from the Nor Slope will be enough to restore o position of self-sufficiency in petr leum energy."

DR. WILSON M. LA
Director, Office of Oil and
Department of Int
March, 1

1971

"Domestic oilmen have taken prom. and effective action to prevent an in pending petroleum shortage duri the current winter, but there is re son for serious concern over th nation's long-term energy supp outlook."

FRANK N. IK
President, American Petroleum Inst
January 9, 1

1972

"Already there are many indications that the energy crisis is not simply impending—it is here now and it must be dealt with now."

THORNTON F. BRADSHAW
President, Atlantic Refining Company,
testifying before the Senate Committee
on Interior and Insular Affairs
April 11, 1972

1973

"Importing relatively cheap and abundant foreign crude might have delayed this situation, and traditionally certain politicians for years have enunciated this as a anacea to the energy situation. I suppose politically this made sense . . realistically, it was sheer nonsense."

KENNETH C. REED
President, Apexco Inc.
March 24, 1973

So you see the warnings have been coming for 20 years.

If you are concerned about the supply of gasoline for your car, or the supply of fuel oil to heat your home, or the increasing prices of both, I cannot give you all the answers. I can tell you, however, that you probably don't realize how lucky you are to live in the Missouri area. We haven't really felt the shortage of gasoline or heating oil; neither have we had excessive price increases of these products yet. We probably have more to come. But I have been in New York three times in the month of February and March and I have seen the eleven block long lines, three lanes deep, all pointed toward the same filling station. I have seen the "car sitters" in action.....I hope we do not get into that position here.

While I am not an expert in the oil business, I believe the industry is facing a severe logistics problem. The crude is not always where immediate refining capacity is - the market is not always where the refined products are. So it then becomes a problem of transportation and distribution. This is the reason energy czar Simon has been saying his office would probably have to re-allocate supplies of gasoline and oil from certain proints to places other than normal market areas.

Those of us in the fuels industries have recognized for twenty years or more that an energy crisis was developing, and we have made it our business to keep aware of the progressively declining reserves of petroleum and natural gas, the delays in the development of nuclear energy systems, and the general deterioration of the conventional energy sources except coal. It came as no surprise to us in the coal industry, and neither was it surprising to those in the oil and gas business, who I am sure know as much about coal reserves as we know about their situation. The Arab oil embargo simply accentuated the situation a little earlier than was anticipated.

Now, what about coal in this nation's present energy dilemma and in the longer term outlook? Of the total domestic coal reserves of 3.2 trillion tons, about 400 billion tons are commercially mineable under today's technology. These reserves are widely distributed throughout the United States and Alaska. The higher quality coals, those with a BTU content of 12,000 to 14,500 are found in the Appalachia Region in the Eastern part of the country. Those with 11,000 to 12,000 BTU are generally found in the Midwestern Region. The Western states of the Rocky Mountain Region, however, have vast quantities of low sulfur sub-bituminous coals ranging from 8,000 to 8,500 BTU, much of which occurs in seams up to 100 feet thick, and within 100 feet of the surface. Based on coal consumption in 1973, the total of these mineable reserves would last about 800 years!

To put it another way, our total domestic energy reserves, of all forms, conservatively estimated and measured in terms of BTU's, are approximately as follows:

Coal	80%
Shale	8%
Natural Gas	6%
Oil	3%
Uranium	3%

On the same conservative basis, our domestic consumption is:

Oil	46%
Natural Gas	32%
Coal	17%
Hydroelectric	4%
Uranium	1%

Nearly 80% of our consumption of energy must be in a liquid or gaseous form but less than 10% of our indigenous reserves occur in that form. It is only logical to conclude, then, that we must either change our consumption, mix or convert the only remaining fossil fuel - - coal - - to liquid and gaseous forms. The only alternative is to import petroleum and liquid natural gas. This would result in the disastrous negative balance of payments approaching 100 billion dollars a year, based on today's oil import prices, not to mention the tremendous loss of jobs in this country. Furthermore, this nation cannot afford to continue in this dependent position if we are to remain the world's number one independent industrial power.

As many of you may know, the basic scientific processes to convert coal to synthetic substitutes for oil and natural gas have been around for many years. The Germans ran their war machine in World War II on synthetics from their own coal. Some further refinements are needed to make the substitutes compatible with our own fuels, to be sure, but the research to solve these problems is nearing completion right now. Today it is entirely feasible to anticipate synthetic gas within the next five years, and synthetic crude very shortly thereafter.

The future looks good for these coal conversion uses, and they could well account for 750 million tons of coal production themselves by 1985. Continuation in the projected growth of the electric energy industry alone will probably result in requirements of 650 million tons of coal by 1985, so that with the combined requirements of the electrical industry, the synthetic fuels industry, and the other conventional coal uses, the total coal demand could reach 1.5 billion tons per year by that date, or about three times the output of last year.

Before all these things can come about, however, certain things must be done to preserve-- or indeed to improve the viability of the coal industry.

First of all, we must be permitted to mine the coal, and this includes surface mining as well as underground mining. Surface mining now accounts for more than 50% of the total United States production. This matter rests today largely in the hands of the Federal Congress, which is currently considering legislation to curb or restrict surface mining, or quite possibly prohibit it entirely.

Secondly, the coal users must be allowed to burn the coal as coal, without the threat of punitive penalties, or shutdown for want of a pollution-free substitute. There are no more substitutes!

The industries that consume coal should be allowed to continue the practice until technology is developed for the removal of sulfur from stack gases, or from the fuel itself, and not be required to make overwhelming investments in processes and equipment that are neither proved nor practical in application. These techniques will come, of course, but there is no possibility of their development by July 1, 1975, barely a year away, when the E.P.A. emission standards are scheduled to become effective. These standards, by the way, are such that coal would have to contain less than 1% sulfur to meet them, and this low sulfur coal simply is not available.

Thirdly, let's look at the business aspects of this problem. The coal industry today, with its high level of mechanization is extremely capital intensive. It costs from $10 to $15 per annual ton to build a mine today, so for a five million ton mine we are looking at a 50 to 75 million dollar investment.

No coal company will build, and no financial institution will underwrite a coal mine to produce millions of tons per year of high sulfur or low sulfur coal unless the company has a guaranteed market, or at least a guarantee of market availability, for the life of the coal mine. To do otherwise would be financial suicide.

Now, transportation. There are several problems in transporting coal and they are real, at the present time; for the longer term, they are not insolvable. Today, there is a shortage of railroad cars, as much as 40% at some mines and on some railroads, while at other mines, on other railroads, there has been a shortage of both cars and the locomotives to pull them. I am sure the railroads will make a valiant effort to improve their car and locomotive supplies through more timely maintenance, more complete reconditioning, and new acquisitions to meet the challenge of growing coal movements from greater production, if they can be assured of the continuance of the service sufficient to amortize these investments. Some railroad officials have stated publicly, however, they will not make such investments on a short term basis. You can see, therefore, that the railroads' interests run parallel to those of the mining industry, and for the same reasons.

I might add that the circumstances in the barge transport industry are almost identical.

I know from experience in our own company, that currently the lead time from placing an order to time of delivery of either railroad cars or barges is at least two years. For the long term, I think the problems of transport can be overcome. Mine mouth consumption will obviate some transport requirements. Increased use of coal slurry pipelines can alleviate the problem in other areas. But if the coal industry expands as President Nixon has indicated, I am sure all transportation capabilities will be taxed to the utmost.

My remarks to you would not be complete without some brief comment on "Coal versus Nuclear." It is difficult to predict if one has a more optimistic future than the other. For the near-term, and the mid-term, through the end of this century, I think even the Government's atomic energy experts hold the opinion that the nation will have to rely heavily on coal to meet its energy requirements. Let's face it! Nuclear fission, which is atomic power as we know it today, would consume all the known uranium reserves in about 10 to 15 years, and the breeder reactor still is not a reality.

But the coal is here, available, and mineable, now, and for a great deal longer period than 30 years, more like 300 years if we produce 1.5 billion tons, annually. I think also that coal has an extremely optimistic outlook in the synthetic fuels industry as far ahead in the future as we are permitted to see, even with a more rapid advent of nuclear power.

Now, let's look at the time-table for coal development - - Has the energy crisis changed it?

I don't think the energy crisis in the context of the Arab embargo has changed the time-table in the last five months. Peabody has been involved in gasification research, commitment and planning for at least five years, and the present energy shortage has not changed that program.

Speeding up the time-table still rests largely in the Federal and State governments. If restrictions can be eased in coal usage pending technological developments, if requirements in mine planning and in reclamation planning can be streamlined to eliminate needless delays, if the government wants to encourage rather than to deter coal mining, then I think the time-table might be substantially shortened.

Energy independence for the United States can be accomplished - - not by 1980 in my opinion, as President Nixon has predicted - - but perhaps by 1985, if we start now with a well-defined national policy.

Gentlemen, I have already told you, "We have run out of substitutes"---COAL is the answer, and half of the world's supply lies right here in these United States. Coal can, and it appears now that it will, pull this nation's energy chestnuts out of the fire.

COAL GASIFICATION AND LIQUEFACTION

Sam Friedman
Assistant Research Supervisor
Pittsburg Energy Research Center
U. S. Bureau of Mines
Pittsburg, Pa.

ABSTRACT

The current major processes being developed for coal gasification and liquefaction will be reviewed briefly. The Bureau of Mines Hydrane process for converting coal to pipeline quality gas directly by reaction with hydrogen will be discussed in more detail. The featured topic will be the Bureau's Synthoil process which converts coal in one step into a low-sulfur, low-ash fuel oil. Coal suspended in recycled oil is propelled through a packed-bed reactor by rapid turbulent flow of hydrogen. A 1/2 TPD plant is in operation producing over 1 bbl of oil per day.

HYDROGEN - AN EMERGING ENERGY CARRIER

James E. Funk
College of Engineering
University of Kentucky
Lexington, Kentucky

ABSTRACT

The "hydrogen economy" envisions the energy needs of the United States in the early part of the next century being served by a network of nuclear plants producing electricity, hydrogen, and perhaps desalted water. Hydrogen is a very attractive synthetic fuel and offers appealing features as an energy carrier. This paper considers a number of factors involved in the expanded use of hydrogen including supply and demand, production techniques and transmission and storage.

INTRODUCTION

The three major energy carriers in the U.S. today are electricity, natural gas and petroleum liquids, mainly gasoline. The use of these energy carriers has developed over the past fifty years and their distribution systems are now quite well established - high voltage lines for electricity, an extensive pipeline system for natural gas, and numerous local outlets for petroleum products.

These three energy carriers either are, or depend heavily upon, fossil fuels. The use of fossil fuels, especially petroleum and natural gas, will have to diminish as these resources are depleted. The production of fossil fuels worldwide is predicted to peak between 2020 and 2050 and alternative energy sources and carriers are now actively being sought. These include nuclear power - both fission and fusion, coal and coal gasification and liquefaction, and solar and geothermal.

A renewable synthetic fuel which is easily transportable will probably be a necessity in the 21st century and hydrogen is a very attractive candidate. As a fuel, hydrogen burns invisible and cleanly, the primary combustion product being water which is easily and compatibly returned to the environment. Hydrogen can be transported in existing or newly constructed pipelines at a cost estimated to be roughly 2.5 times the cost to transport the same amount of energy as natural gas. While expensive, the cost is less than transmission of electrical energy by any means. Hydrogen can be stored as a gas, a liquid, or as a metal hydride and could conceivably replace fossil fuels for all combustion uses.

Hydrogen is not, of course, a primary energy source in the same sense as coal or uranium. Except for that which is produced in association with petroleum, hydrogen must be produced from water or water and another fossil fuel, usually by steam-methane reforming or partial oxidation of petroleum liquids. Electricity is produced from a primary energy source and in the long term hydrogen will also have to be produced from a primary energy source. Water will be the only raw material and hydrogen will be produced either electrolytically or thermochemically.

Many comprehensive and detailed studies dealing with hydrogen and the many aspects of a "hydrogen economy" have been published recently[1-5] and much of the information and data presented in this paper has been taken from these references.

Supply and Demand

Table I, taken from Meadows and De Carlo[6] and the Office of Coal Research[7], shows past usage and forecasted demand for hydrogen. The large range in forecast for the year 2000 results from uncertainties in the demand for hydrogen for petroleum refining and for the gasification and liquefaction of coal. Table II shows the distribution of hydrogen and uses for 1968 and 2000.

TABLE I

Future and Historical Hydrogen Demand

Year	U.S. (Billion SCF)	Rest of World (Billion SCF)
1955	378	-
1960	563	-
1965	1015	-
1968	2060	3000
1970	2390	-
1975	4790	-
1980	5740	-
2000	15,000-53,000	25,000-64,000

TABLE II

Hydrogen End Use in the U.S.

	1968	2000	2000
Ammonia	42%	40%	7%
Petroleum Refining	38%	37%	53%
Chemicals, Hydrogasification, Iron Ore Reduction, etc.	20%	23%	40%
	100%	100%	100%
Billions of SCF	2,060	15,000	53,000

These projections have not taken into account the increased demand which would be generated by uses envisioned in the "hydrogen economy." For example, if one half the projected deficit in natural gas in the year 2000 were to be supplied as hydrogen, an additional 26,000 SCF/year would be required. 5,900 SCF/year would be required in the year 2000 should hydrogen be used as a fuel for 10% of U.S. air transportation.

Production Techniques and Costs

State of the art technology provides two techniques to produce hydrogen. The first is by the reaction of water with a hydrocarbon such as steam-methane reforming or partial oxidation of petroleum liquids. These processes are very well developed and the hydrogen cost depends heavily on the cost of the hydrocarbon raw material. Table III shows production costs for various synthetic fuels. It can be seen that producing hydrogen from methane adds roughly 60¢ per million Btu to the cost of the product. Partial oxidation, not shown in Table III, produces more expensive hydrogen than steam-methane reforming.

TABLE III

Synthetic Fuel Production Costs

Fuel	Production Process	Fuel Cost ¢/million Btu
Hydrogen	Steam Methane Reforming, Methane at 40¢/MSCF	100
	Coal Gasification, Coal at 7$/ton	130
	Lignite, 2$/ton	80
	Water Electrolysis	
	2.5 mills/kwhr	230
	8 mills/kwhr	230-520
	Advanced Technology, by-product credit, and 8 mills/kwhr	170
Methanol	Natural Gas at 40¢/MSCF	160
	Coal, 7$/ton	150
Methane	Wellhead	15-40
	Coal Gasification	80-100
Ammonia	Natural Gas at 45¢/MSCF	160

Source: Hydrogen and Other Synthetic Fuels, USAEC, TID 26136, UC-80, September, 1972

The second technique, water electrolysis, is also fairly well developed, but is quite expensive. In an advanced type electrolyzer 71% of the net manufacturing cost is for electric power. In a plant producing 44,000 lb H_2/hr (200 million SCF/day) the production cost would be about $3.30/million Btu (108¢/MSCF). Capital investment for such a plant would be approximately 40 million dollars, which can be compared to the cost of the associated 1000 MW electric generating plant of about 340 million dollars.

Hydrogen via coal gasification may be attractive in the short term and cost estimates indicate that it may be relatively inexpensive. A plant to produce 200 million SCF/day of hydrogen from coal is estimated[3] to cost about 44 million dollars and to yield production costs of about $1.50 per million Btu using 10$/ton coal.

Table IV shows the delivered cost of energy in the form of natural gas, electricity, and electrolytic hydrogen and clearly displays the incentive for research in the area of thermochemical decomposition of water. The energy efficiency of producing electrolytic hydrogen is relatively low, in range of 25-30%, because of the low thermal efficiency of generating electricity from a primary energy source. In thermochemical processes the objective is to use thermal energy directly in a chemical process comprising a series of chemical reactions and the associated separation stages. Research is now underway in the U.S., Europe and Japan with the objective of developing thermochemical water decomposition processes which will deliver high thermal efficiencies and, hopefully, lower operating and capital costs.

TABLE IV

Price of Delivered Energy

$ per million Btu

	Electricity	Natural Gas	Electrolytic Hydrogen
Production	2.67[1]	0.17	2.9-3.2[2]
Transmission	0.61	0.20	0.52[3]
Distribution	1.61	0.27	0.34
Total	4.89	0.64	3.8-4.1

[1] 9.1 Mills/kwhr

[2] Using 9.1 mills/kwhr electricity

[3] H_2 at $3/million Btu as compression fuel in optimized pipeline, compared to natural gas at $0.25/-million Btu

Source: Gregory, D. P., A Hydrogen Energy System, American Gas Association, Cat. No. L21173, August, 1972

Transmission and Storage

The transmission of large quantities of hydrogen over fairly short distances is a common industrial practice. The Chemische Werke Huls AG in the German Ruhr operates a 130 mile hydrogen pipeline network. The system operates at 150 psig with an annual throughput of about 10 billion SCF.

U.S. companies, including Air Products and Chemicals and Linde, operate short hydrogen pipelines and have indicated[2] their belief that operation of longer pipelines would not present insurmountable technical problems. Currently available natural gas pipelines would not necessarily represent optimum configurations for the transmission of hydrogen, either in terms of size or location of compression stations. The Institute of Gas Technology has estimated[2] that a fully optimized pipeline system could transmit hydrogen at a cost of 3.5 to 4.5 ¢/million Btu per 100 miles at an average pressure of 750 psig. This cost could be reduced by about 30% if 2000 psi operating pressures could be used.

The question of the effect of hydrogen on materials of construction is still open. Classical "hydrogen embrittlement" has not been a problem with existing mild steel pipelines. NASA, however, has recently identified a phenomenon termed "hydrogen environment embrittlement," so named to indicate the effect of hydrogen on the surface of materials rather than the effect of hydrogen when it is present within the material. NASA experienced failures in high pressure storage vessels containing very high purity hydrogen. These frequently occurred, however, in welded sections and this sort of failure has not been experienced in normal high pressure "bottles" which are typically one piece forged units. While a number of materials, including titanium, aluminum and copper alloys and certain stable austenitic stainless steels (316, 347, A-286), have been identified as not susceptible to hydrogen environment embrittlement, more research on this subject is required to completely clarify the situation.

Hydrogen can be stored underground in depleted natural gas fields, salt or mined caverns or above ground in bottles or pressure vessels. Work is being done at the Brookhaven National Laboratory on storage as a metal hydride. Capital costs for hydrogen storage, because of its lower heating value, are higher than for natural gas, typically by a factor of 3 to 5. Reference 2 provides a detailed discussion of hydrogen storage, including liquefaction.

The Future

Movement toward the greater use of hydrogen in commercial, industrial and residential situations will be strongly influenced by varying economic conditions. Production costs may be the prime determinant in the development of a hydrogen economy and much work is being done on this problem today. The steady and sure depletion of our reserves of fossil fuels, however, will exert strong pressure to develop synthetic fuels. Environmental considerations will require that the synthetic fuel be clean and nonpolluting. Hydrogen meets these requirements and we may expect to see increased emphasis on its production and use in the near future.

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ENERGY FROM BIOCHEMICAL SOURCES

G. J. Fennewald D. L. Million E. L. Park J. L. Gaddy
University of Missouri
Rolla, Mo.

ABSTRACT

As available energy reserves decline, renewable sources must be utilized. Organic matter, grown agriculturally, represents a renewable energy source, which is readily available. This paper reviews the methods by which organic matter can be converted to energy sources by biochemical processes. The economics of conversion of agricultural crops and by-products to alcohols by fermentation and conversion of these agricultural materials to methane by anaerobic digestion are examined. Projections of the potential of this energy source are quite promising.

INTRODUCTION

During the past few years, we have seen demand for energy and petrochemicals grow at a pace so rapid that we now realize that reserves of fossil fuels, which were once considered inexhaustible, are being quickly depleted. The world's reserves of petroleum and other carbonaceous material was built up over a period of millions of years from the only source of carbon which is continuously available, CO_2 in the atmosphere. Plant life uses the carbon in CO_2 along with H_2 and O_2 from water to build cellulose, sugars and protein. Because we can no longer afford to wait for nature to convert plant life into coal, oil or gas, which are readily usable as energy and raw materials, more direct ways must be found to use this source of energy.

There are large quantities of agricultural by-products from food producing operations that today represent a waste disposal problem. In addition, unused cropland can be put into production. Both these sources represent a significant renewable source of organic matter available for conversion into energy.

Processes For Energy Conversion

A number of processes are available for converting agricultural products or by-products into energy forms and chemical feedstocks.

Plant material may be burned directly in a boiler to generate electricity. Drying would probably be required to reduce the moisture content so that efficient combustion temperatures could be achieved. Although the exhaust gases would be essentially sulfur free, there are many other disadvantages associated with direct combustion of plant material. These disadvantages include transportation and dry storage during the non-growing season and the possible redesign of boilers to accomodate low BTU content fuel.

Methods have been developed for converting organic material into other energy forms. These energy forms are more suited to transportation and storage and also offer the added potential of serving as petrochemical feedstocks.

Organic material may be converted to a low-sulfur fuel oil in a high temperature, high pressure liquifaction process developed by the Bureau of Mines. In this process, the organic material is treated with carbon monoxide at temperatures from 25-400°C and 2000-5000 psi pressure. One disadvantage of this process is the high temperature and pressure involved. Of the available energy from direct combustion of the organic matter, only 35 percent is available in the processed fuel oil[1].

A similar process for converting organic wastes to a usable form of energy involves gasification to methane. A temperature near 750°F and a pressure around 1000 psi are required[1,2]. About 1.7 scf of hydrogen are consumed per scf of methane produced. This process also suffers from a significant reduction in energy availability.

Biological processes can be used to convert wastes to methane, ethyl alcohol, acetic acid, furfural and a variety of other chemicals. Of these methods, fermentations of hydrolyzed cellulosic materials to alcohol, furfural and acetic acid, and anaerobic digestion of various substrates to methane have been demonstrated commercially. These processes result in recovery of 70-90 percent of the energy available in the raw material[3,4].

The purpose of this study is to demonstrate the potential of biological processes for the conversion of agricultural by-products to energy forms and chemical feedstocks. Economic analyses of the alcoholic fermentation and anaerobic digestion processes are presented. The basis of this study is published data available for these processes and data from the research laboratories in the Chemical Engineering Department at the University of Missouri-Rolla.

Alcohol Fermentation Process

The alcoholic fermentation process involves converting such carbohydrates as cellulose, starch, and sugar to alcohol. Materials such as wood, corncobs, oathulls, straw and other roughage contain primarily cellulose, hemicellulose and lignin. The hydrolysis of cellulose and hemicellulose is catalyzed by sulfuric acid which does not affect the lignin.

The description of a fermentation process using corncobs is presented in Figure 1[3]. In this process, the cobs are crushed and carried countercurrent to a solution of hot 5 percent sulfuric acid by a screw conveyor in the pentosan hydrolyzer. About 95 percent of the pentosans are converted to xylose in a 15 percent solution which may be further processed to furfural and acetic acid.

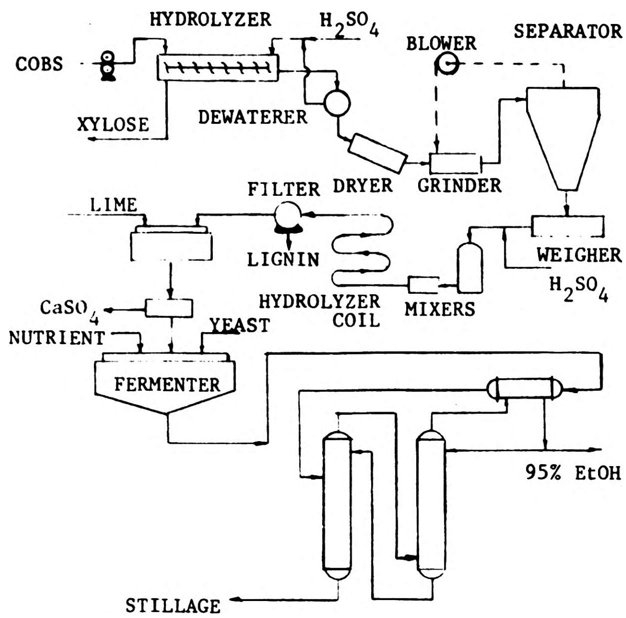

FIGURE 1. ALCOHOLIC FERMENTATION PROCESS

The remaining solids are dewatered, dried and ground. The fine powder is sprayed with about one-third its weight of 85 percent sulfuric acid in a water-cooled mixer. This mixture is then plasticized in a screw press impregnator, mixed with 10 parts cold water and pumped into steam heated coils where the hydrolysis of the cellulose is completed. The slurry is filtered to remove the lignin, neutralized and filtered to remove calcium sulfate before the clear glucose solution is fed to the fermenters. Yeast and nutrients are added to initiate alcoholic fermentation. The material from the fermenters is purified to 95 percent ethyl alcohol in a two-step distillation.

The xylose solution may then be converted to furfural and acetic acid in a process described in Figure 2[5]. The dilute feed solution of xylose and acetic acid is preheated and brought to reactor temperature by the injection of high pressure steam. Following

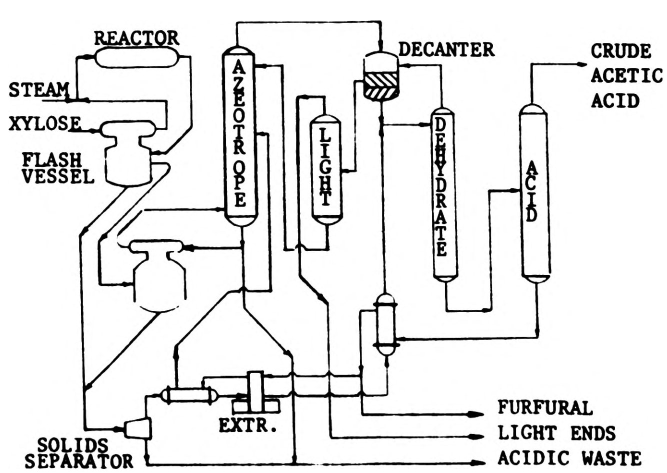

FIGURE 2. FURFURAL AND ACETIC ACID PROCESS

reaction, the solution is flashed to supply heat to the azeotrope column and incoming feed. The solids are removed and the solution is cooled before entering the extractor. In the extractor, the dilute solution of furfural and acetic acid is contacted with cooled anhydrous furfural.

A raffinate solution consisting of about 8 percent furfural and a small amount of acetic acid is charged to the azeotrope tower for recovery of furfural. The azeotrope from the column is broken by allowing the condensate to separate into two phases, 18 and 87 percent furfural. The dilute phase is returned to the azeotrope tower as reflux.

The extract, 87 percent furfural, is mixed with the rich phase from the azeotrope column and the water is removed in the dehydrating column. The acetic acid-furfural mixture from the dehydrating column is separated in the acid column. The furfural stream is split so that a portion leaves the system as product and the rest recycles as a solvent.

An economic evaluation of the manufacture of 3,500,000 gallons per year of ethyl alcohol, 21,700,000 pounds per year of furfural, and 9,770,000 pounds per year of acetic acid from corncobs is presented in Table 1. This evaluation is based on the data presented by Arnold[3] and Harris[5]. Adjustment has been made for increasing investment and operating costs to present day levels. Today's market value was used for raw materials and products. An investment of $6.50 million is required for this plant. Operating costs of $4.88 million are estimated including about $480,000 for 79,500 tons of corncobs. A surprising return on investment of 19.5 percent is estimated with a payout of about 5 years. It should be emphasized that this analysis is based upon present prices for products. Projected future increases in prices for energy and petrochemicals provide added economic incentive for producing energy by fermentation.

Table I. Economic Evaluation of Alcoholic Fermentation Process

PLANT INVESTMENT	$6,500,000
REVENUE	$6,502,000
Direct Costs	
1. Raw Material Cost	
Corncobs	477,000
Sulfuric Acid	156,000
2. Utilities	
Steam	956,000
Water	94,000
Electricity	106,000
3. Operating Labor	696,000
4. Supervision	209,000
5. Payroll Burden	272,000
6. Maintenance and Supplies	868,000
Fixed Costs	
1. Taxes and Insurance	145,000
2. Depreciation	592,000
TOTAL PRODUCTION COST	$4,601,000
Sales Expense	274,000
TOTAL OPERATING COST	$4,875,000
GROSS PROFIT	$1,627,000
NET PROFIT	$ 813,000
RETURN ON INVESTMENT (Percent)	19.5
PAYOUT (Years)	5.2

An estimated 640 million tons of agricultural organic wastes are available from processing crops in this country[6]. If 10 percent of this amount were readily available and could be used for alcohol fermentation, 1.5 million gallons of alcohol could be produced.

On a BTU basis, this is the equivalent of roughly 150 million barrels of crude oil, or about 5.4 percent of the petroleum consumed for transportation in this country in 1970. Alcohol may be added to gasoline in amounts up to 10 percent without greatly affecting engine efficiency while requiring only minor engine adjustments[7]. Ethanol, furfural and acetic acid also may be used as starting materials to synthesize a wide variety of chemicals such as synthetic rubber, plastics, solvents and drugs.

Methane Production By Anaerobic Digestion

The formation of methane in the decomposition of organic compounds is brought about by the action of methane producing bacteria. Investigations into the nature of the reactions has lead researchers to believe that anaerobic digestion of a complex substrate proceeds in three steps. First, enzymes convert the solid organic material to soluble organic compounds. These soluble carbohydrates, proteins, alcohols and fats are then fermented to organic acids which are further metabolized by methane bacteria to CO_2 and methane.

Most investigations of anaerobic digestion have been concerned with disposal of sewerage and feedlot wastes and considerable data is available on these substrates[4,8]. Data is somewhat more limited on the production of methane from other agricultural wastes, although it has been shown that anaerobic digestion of such materials as cannery wastes, molasses[8] and algae[9] is feasible.

A recent study at the University of Missouri-Rolla has demonstrated quantitatively the feasibility of producing methane from hay. These investigations, covering a period of about 6 months, started by digesting manure and gradually replacing the manure fed to the reactors with hay, until the reactors were operating on 100 percent hay. About 30 days operation on pure hay were attained. A similar reactor was operated simultaneously on pure manure. Both reactors were maintained at 95°F and were operated with a 10 day retention time. The results of this study are presented in Table II. It is significant to note that 12.5 scf of gas (or about 8 scf of methane) is obtained per pound of volatile solids destroyed.

Table II. Results of Anaerobic Digestion of Hay

	Reactor 2 Hay	Reactor 3 Manure
Reactor Volume, liter	6	6
Reactor Temperature, °F	95	95
Feed Rate, ml/day	600	600
gm VS*/day	25	25
Feed Composition, mg VS /liter	83,267	83,267
mg/liter BOD_5	7,087	7,087
Effluent Rate, ml/day	600	600
gm VS /day	13.4	13.98
Effluent Composition, mg VS /liter	22,333	23,300
mg/liter BOD_5	1,171	1,351
Total Gas Production**scf/day	0.320	0.250
Gas Production, scf/lb VS destroyed	12.5	10.3

*VS - Volitile Solids
**65% CH_4, 35% CO_2

A process to produce 8 million scf/day of methane anaerobically from hay is shown in Figure 3. This

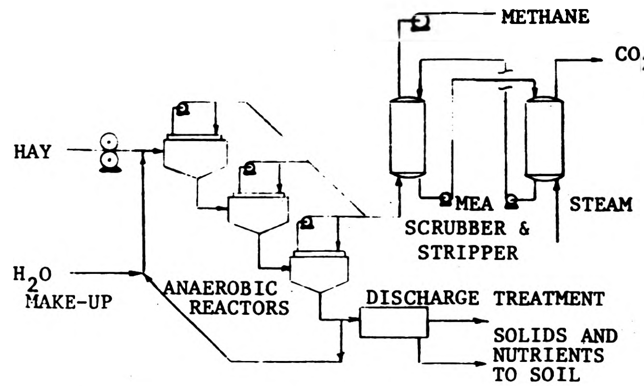

FIGURE 3. ANAEROBIC METHANE PROCESS

process includes a grinder or shredder to prepare the waste material, reactors or holding tanks where the conversion to methane takes place, a monethanolamine scrubber system to remove the CO_2 from the gas produced and compressors to bring the methane to pipeline pressure. Provision must be made to treat the reactor effluent to meet water quality standards for disposal or to dewater the solids, recycle the liquid and return the solids to the soil as fertilizer. An activated sludge process is included for this purpose.

Table III presents an economic analysis of the process shown in Figure 3. An investment of about $2 million is estimated to be required to produce about 3 billion scf/year of CH_4 from 4,250 tons of hay. This plant was designed using the data from Table II. Reactors were designed using kinetic data for digestion of manure[4] since more data were available for this substrate and the digestion characteristics are noted to be quite similar.

Table III. Economic Analysis of Methane Production from Hay

PLANT INVESTMENT	$1,940,000
REVENUE	$3,650,000
Operating Costs	
Raw Material	2,130,000
Anaerobic Digestion	154,000
Waste Treatment	30,000
Compressors	995,000
MEA Scrubber and Stripper	85,000
Maintenance, Supplies, Taxes and Insurance	272,000
Depreciation	159,000
TOTAL PRODUCTION COSTS	$3,205,000
GROSS PROFIT	$ 445,000
NET PROFIT	$ 223,000
RETURN ON INVESTMENT (Percent)	19.7
PAYOUT (Years)	5.1

Operating costs for this process are estimated to be $3.2 million including $2.13 million for hay. About 20,000 bales of hay or straw are consumed per day in producing 8 million scf of CH_4 from this process. A cost of hay of $.25/bale is based upon use of wheat straw available in large quantities in the Midwest. This cost is also not unreasonable for mass production of hay from idle grasslands. The cost of cutting, storage and transportation are included.

Revenue from the process is based upon a methane price of $1.25/million BTU, which is being used as a future price of energy from LNG[10,11]. Based upon these estimates, a return on investment of about 20 percent is available.

It should be pointed out that anaerobic digestion has not been studied from the standpoint of production of methane, rather this process has been studied primarily as a waste treatment method. Therefore, considerable improvement in gas yields and reaction rates might be expected. These are matters under study in our laboratories.

The economics of methane produced by anaerobic digestion are highly dependent upon the price of raw materials. Studies are planned to determine the best type of agricultural raw material to be used in this process. Of course, by-products, such as those proposed for alcohol fermentation, can be utilized with a significant improvement in the economics.

In this nation, the natural gas deficit is forecast to be about 5 trillion scf/year by 1977, or about one third of our consumption[12]. If use could be made of all available crop waste (640 million tons per year), we could produce more than enough CH_4 to make up the deficit. In addition there are vast quantities of materials such as wheat straw or corn stalks that can be utilized as sources of methane. There is also the potential of placing new land into cultivation of agricultural products for conversion to methane.

SUMMARY AND CONCLUSIONS

The economic potential of biological production of energy from agricultural products or by-products is seen to be surprisingly good. Improvement in anaerobic processes is expected to provide added economic incentive for this process. As naturally occurring fuels and petrochemical feedstocks are depleted, use can be made of agricultural raw materials which can be converted into a variety of energy forms.

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STATUS AND OUTLOOK FOR ENERGY CONVERSION VIA FUEL CELLS

John P. Ackerman
Argonne National Laboratory
Argonne, Ill.

INTRODUCTION

Fuel cells have the potential of providing good solutions to a variety of energy-related problems. As our supplies of conventional fossil fuels are depleted, their cost will rise, and there will be increasing difficulty in obtaining certain premium fuels at any price. It behooves us, then, to use our remaining reserves of fuels as efficiently as possible. Energy conversion via fuel cells represents one of the best ways to achieve this goal, because it is possible, simultaneously, to obtain more work and less pollution from a dollar's worth of fuel with a fuel cell than with any other device.

ADVANTAGES OF FUEL CELLS

Although much of the interest in fuel cells is due to their efficient use of fuel, there are considerable pollution control advantages to be gained as well. Because the fuel reacts electrochemically rather than by burning in air, no nitrogen oxides are formed. For the same reason, emissions of unburned and partly burned gaseous and particulate products are essentially nil. The only moving parts in fuel batteries are fuel pumps and, perhaps, electrolyte pumps, so operation is inherently very quiet. There is relatively little thermal pollution because less energy is lost as heat.

The overall efficiencies of a number of systems are compared in Fig. 1.[1] The efficiencies shown in Fig. 1 are generally rather optimistic, and tend to be relatively more so for the low efficiency devices. While there are a number of different kinds of fuel cell systems whose efficiencies vary from somewhat more to considerably less than the 60% shown for fuel cells, the message remains that more useful energy can be extracted from fuel with fuel cells than with any other energy conversion device.

Figure 2, the U. S. energy flow pattern for 1980,[2] shows the incentive for improved energy utilization. While it is difficult to assess what fraction of the energy is used and what is lost, it is clear that there is a great deal to be gained from more efficient use of our energy resources. Almost half of the energy consumption will be "lost" in 1980, projections for beyond 1980 show an even greater fraction lost.

APPLICATION OF FUEL CELLS

The uses to which fuel cells may most profitably be applied are electric power generation and transportation. Most of the non-electrical energy in the industrial sector, and nearly all in the commercial and residential sector is used for heating. Conversion of fuel to heat usually proceeds with high efficiency, so relatively little application of fuel cells in these sectors is seen.

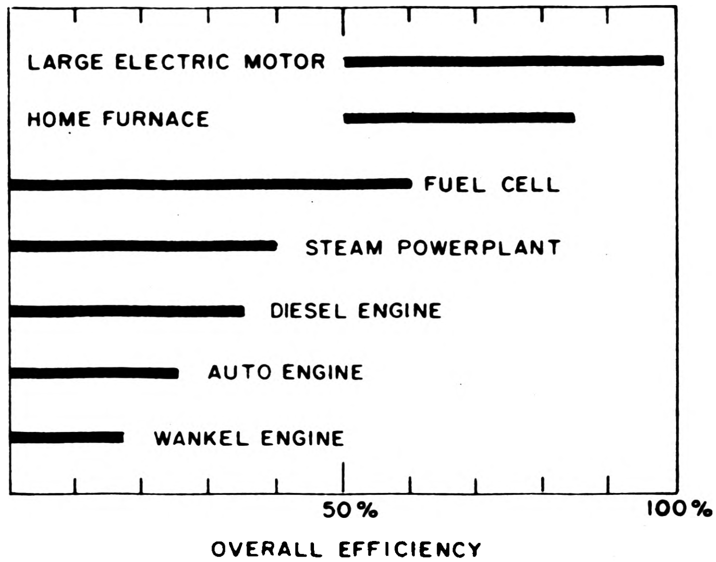

Fig. 1. Efficiencies of Several Energy Conversion Systems.

Because the fuel cells convert chemical energy directly to electrical energy, electrical power generation is probably their most natural application. While the output of each cell is low voltage DC power, cells may be connected in various series and parallel arrangements to give whatever voltage is desired, and large highly efficient inverters are available for conversion to AC.

In this application, fuel cells must compete with large steam turbines, which are remarkably efficient devices. (At rated load, a large modern unit can approach 40% efficiency.) However, the demand for electrical energy is far from constant, as may be seen in Fig. 3.[3] Over the course of a year, the actual power output of a large utility may vary by nearly a factor of four, and the daily variation in load can be almost a factor of three. To adjust to this changing demand, either the large base load plants must sometimes operate at part power, or smaller cycling or peaker units must be used during periods of high demand. Either way, efficiency suffers and pollution increases. Contrast the part-load efficiency of fuel cells and heat engine power plants in Fig. 4. The fuel cell system not only has a greater efficiency at full load, but this efficiency is retained and even increases as load

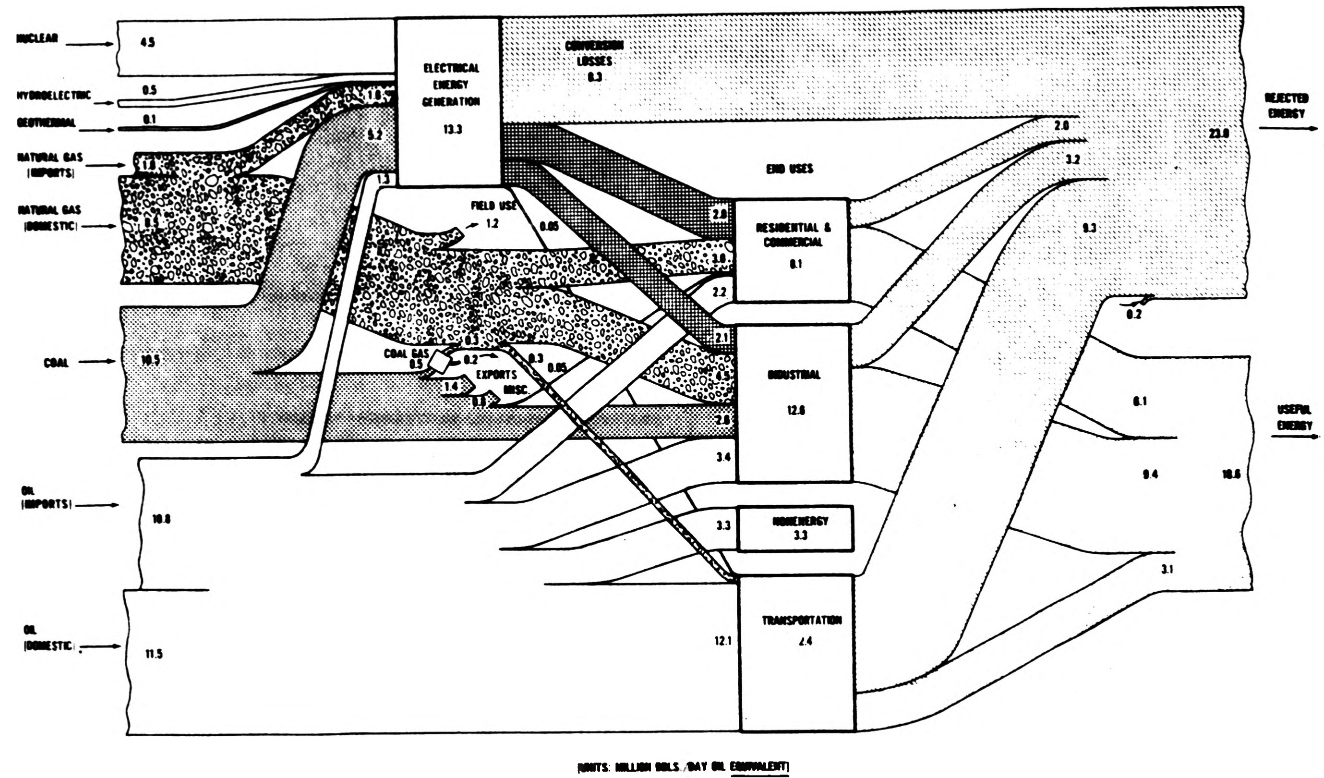

Fig. 2. U. S. Energy Flow in 1980.

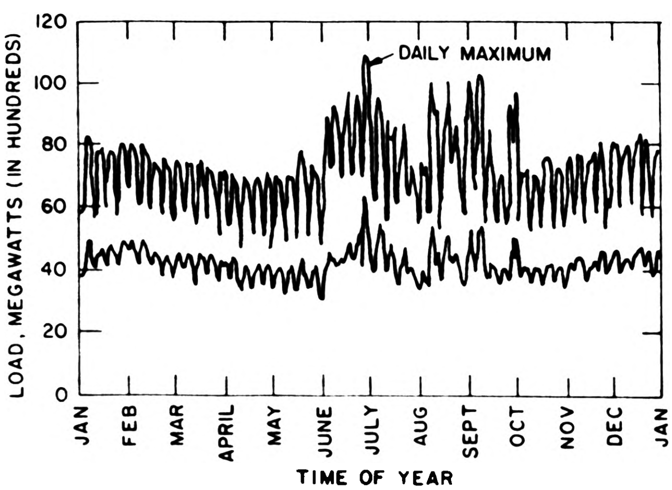

Fig. 3. Variation in Daily Maximum and Minimum Loads. (Commonwealth Edison, 1971)

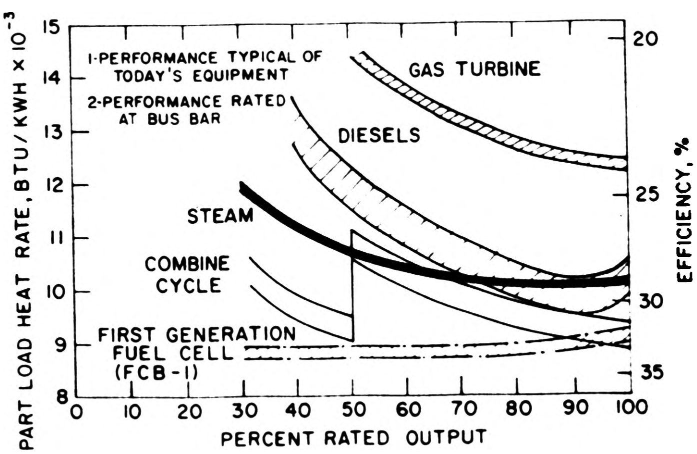

Fig. 4. Energy Systems Comparison (Part-Load Performance)

diminishes, so that inefficient peaking generators may not be needed.

A fuel cell system, unlike a heat engine, need not be big to be efficient. Figure 5[4] shows how efficiency varied with rated capacity for several generating systems. This characteristic, taken together with two others - low emissions and capability of operation on a variety of fuels - allows fuel cell systems to be operated almost anywhere. A small community power company can operate a power plant on the optimum fuel available locally with nearly the same efficiency achieved by a large central power station. A large metropolitan utility can disperse a number of generators throughout its area and match capacity to local demand, substantially reducing the expense and other problems associated with transmission and distribution of electricity.

Some idea of the savings to be made in energy transportation can be obtained from Fig. 6. The costs shown[5] for transporting electrical energy are for long distance transmission of energy. Costs and other problems involved with local distribution of electrical energy are likely to be greater, especially as more utilities go to underground lines in urban areas. Also, the cost of transmission should be reduced by a factor of two rather than three for comparison with fuel cell generating systems, because fuel cells require less fuel per kilowatt hour of electricity gen-

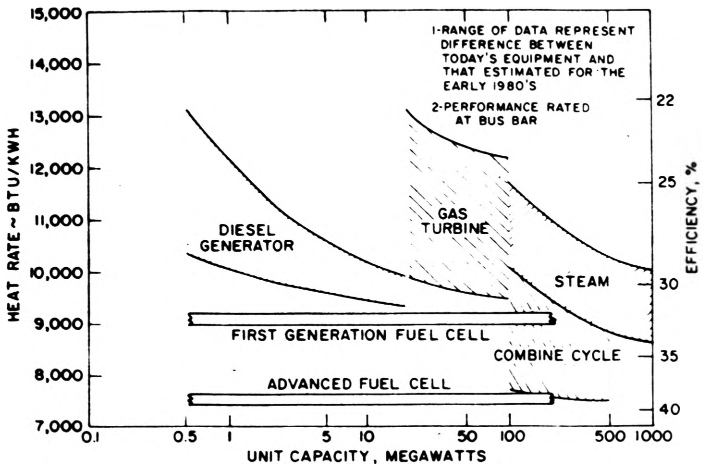

Fig. 5. Energy Systems Comparison (Performance *vs.* Unit Size)

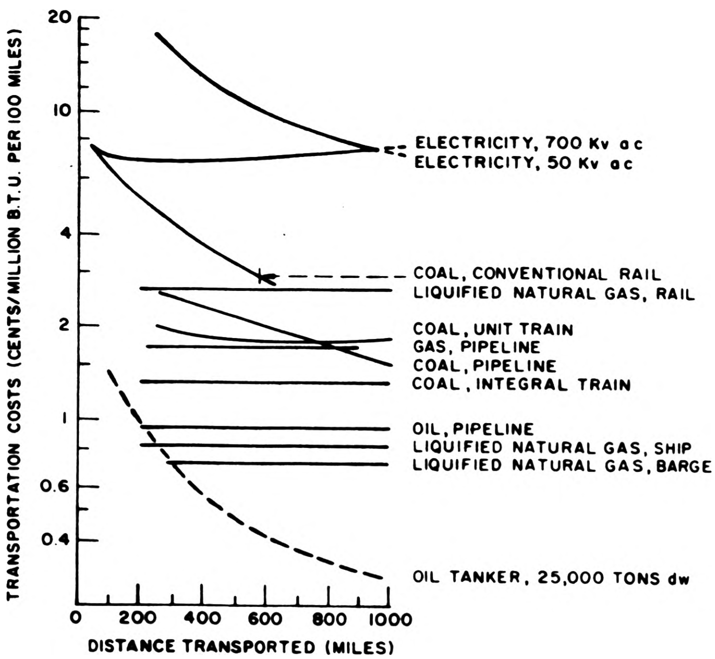

Fig. 6. Costs of Transporting Energy.

erates than do conventional generating stations. This figure was drawn up in 1972, and should be viewed with some appreciation of changing economic conditions, especially in the last year or so.

In the transportation industry, the same virtues of efficiency and low pollution make the fuel cell attractive. Here there are at least two other major requirements which must be met. These are the needs for a relatively high available energy/weight ratio (so-called energy density) and for a large power/weight ratio (power density). Fuel cells may be expected to meet the first criterion handily, since the amount of energy available is determined by the size of the fuel tank. A fuel cell powered vehicle can have a good long range without refueling and can be refueled rapidly, just as can present day internal combustion vehicles. This represents a substantial advantage over battery powered vehicles, which are the competition for efficient, low pollution personal transportation.

The criterion of high power density is considerably more difficult to meet. It is very much worse for small personal vehicles than for large busses, trucks, trains and ships. Figure 7 gives power density/energy density relations for fuel cells, internal combustion engines, and a variety of battery systems. To propel a vehicle of weight comparable to an "intermediate" car with speeds and accelerations usable in present traffic conditions, it is probably necessary to achieve a power density of about 100 watts per pound, which is equivalent to about thirteen pounds per horsepower. It may be possible to meet that goal by hybridizing a fuel battery with one of several high power energy storage devices, such as one of the new generation of flywheels.

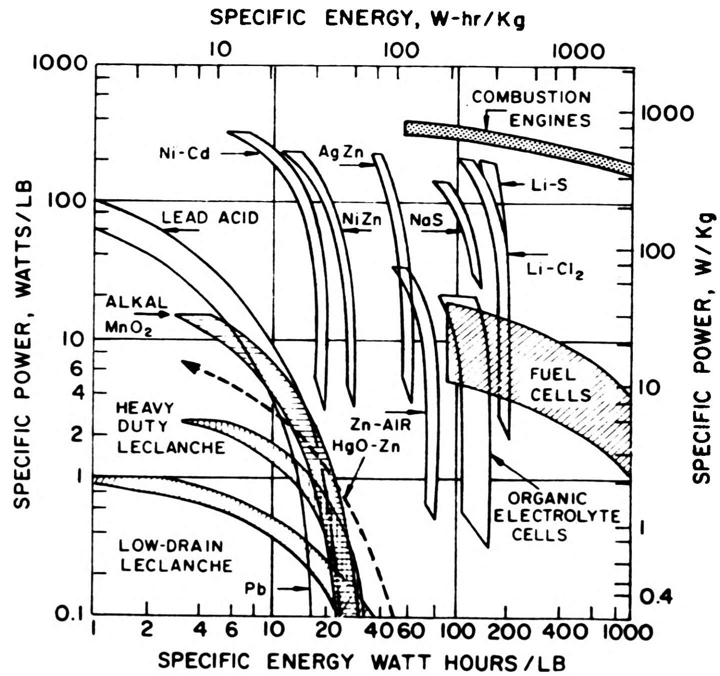

Fig. 7. Energy Density *vs.* Power Density for Several Energy Sources.

Two factors will act to mitigate the necessity for high-power densities. One is increasing cost and decreasing availability of fuel, which is even now limiting the speeds and hence the power required for road vehicles. The other is that the presence on the road of low power vehicles will tend to change driving patterns in the same direction of decreased speed and acceleration requirements.

Fuel cell systems of adequate performance to propel railroad trains, barges, and ships can probably be built with existing technology, at least, as far as cells themselves are concerned. The detailed engineering necessary to actually build the power plant and ensure reliability and control is another matter. Although essentially all of the basic technology is available, considerable effort would have to expended to develop a viable system. The power plant would be very smooth and quiet, virtually pollution free, and could operate on conventional fuels. A detailed economic analysis would have to be undertaken to determine the break-even point where increased fuel costs would balance against lifetime and initial cost considerations.

CHOICE OF FUELS

Fuel cells have been made using a wide variety of fuels; hydrogen, hydrazine, ammonia, hydrocarbons of various sorts, alcohols, natural and synthetic gas, and others. The pragmatic truth of the matter is that the only fuel which performs nearly as well as hydrogen is hydrazine, and hydrazine is both toxic and very expensive. Unfortunately, the hydrogen economy is not yet upon us, and hydrogen is not widely available in large quantities. Technology does exist for conversion of a variety of other fuels to hydrogen where tank or pipeline hydrogen is not available.

Natural gas and petroleum distillates are relatively easy to convert to hydrogen by several processes. One of the best for fuel cell uses is catalytic steam reforming at high temperature (900°C). The raw gas stream contains carbon monoxide, a notorious catalyst poison, which can be removed by the "shift" reaction with steam to form carbon dioxide and more hydrogen. Sulfur must be removed from the feed stream or raw gas stream because it ruins the reforming catalyst, the shift catalyst and the fuel cell catalyst. This is actually somewhat of an advantage, since now there can be no sulfur oxides in the fuel cell exhaust. Sulfur removal technology is well proven and in wide use in the petroleum industry. The pressure and temperature requirements imply that hydrocarbon fuels will be better suited to fixed than mobile uses.

Ammonia can be easily cracked in a simple reactor to provide a very suitable fuel stream containing only hydrogen and nitrogen. The small equilibrium amount of residual ammonia in this stream is easily removed in a trap. The simplicity of the cracker lends itself to easy control and thus, to mobile applications. Ammonia is relatively easy to store, and has a reasonable energy density (2.5 kWh/lb *vs.* 2.76 kWh/lb for methanol and about 5.8 kWh/lb for gasoline).

Methanol has most of the virtues of ammonia, and in addition, can be converted to hydrogen at relatively low temperature (near 250°C) and a pressure near one atmosphere. It is also likely to be less expensive than ammonia (about ten to fifteen cents per gallon at the plant if one has a coal gasification plant that makes high-BTU gas at $1.50/million BTU or less, or if naphtha is available). Methanol is fairly reactive electrochemically, and there is a possibility that it can be used directly in a fuel cell without reforming. It is sufficiently involatile that it can be handled in the present gasoline distribution system without basic changes. All these factors combine to make it the most promising fuel for mobile applications.

As coal gasification technology matures, very satisfactory feed streams for fuel power plants will be available. Present processes convert coal to a carbon monoxide/hydrogen mixture which is scrubbed of sulfur-containing gases and converted to methane. For direct fuel cell use, the carbon monoxide in the sulfur-free stream could be shifted with steam via the water-gas shift reaction to carbon dioxide and hydrogen. The carbon dioxide could be scrubbed from the stream, if necessary, but it would probably be satisfactory to leave it in if the fuel cell station were nearby. If the H_2 were pumped to a remote location it would be removed because of the pumping cost. This stream could also be used in ammonia synthesis; in this case, air would probably be used in the gasification processes to give the correct amount of nitrogen in the gas stream. For synthesizing methanol, carbon monoxide would be left in the stream, since it is one of the reactants in methanol synthesis.

STATUS OF FUEL CELLS

At present, there are essentially no commercial uses of fuel cell power plants in the field of transportation. Dr. Karl Kordesch of Union Carbide Corp. has had a small economy car converted to operate on a gaseous hydrogen fuel battery/lead-acid battery hybrid system for several years, but this is a hobby project, undertaken, perhaps, to demonstrate that it can be done. Six hundred cubic feet of hydrogen gas store 33 kWh of energy, and give the car a range of about 200 miles at 40 mph.[6] General Motors has a fuel cell program which is active and making progress, especially on the air electrodes, but they have not announced any plans for putting fuel cells in even an experimental vehicle in the near future. When sufficient progress has been made that fuel cells of high power density can be constructed, there will doubtless be much more interest from the transportation industry, but at the present there is not sufficient incentive for the automobile makers to launch the large research and development effort that would be required to construct an economically competitive vehicle.

In the utilities field, the situation is considerably brighter. Pratt and Whitney have contracted to put several dozen, 26 megawatt fuel cell power plants in the field for a group of utilities, beginning in 1975. These plants will operate on a variety of fuels; natural gas, methanol, naphtha, or possibly even #2 fuel oil, depending on reformer technology. These are the first commercial units to be developed, and successful application of these plants would mark the beginning of wide-spread use of fuel cells for power generation and the beginning of a new era in our national use of energy.

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OXIDATION REACTIONS OF UNSATURATED HYDROCARBONS FOR FUEL CELLS

J. W. Johnson W. J. James A. K. Agrawal

University of Missouri - Rolla
Rolla, Missouri 65401

Ohio State University
Columbus, Ohio 43210

The anodic oxidation of unsaturated hydrocarbons has been the subject of numerous studies, primarily on Pt and Au electrodes at low temperatures, < 100°C. The complete oxidation to CO_2 is usually the predominant reaction with both H_2O and OH^- having been proposed as the oxygen source. Usually a single study consists of a comprehensive investigation of a single compound on a single electrode or a somewhat limited study of several compounds on a single electrode. A diversity of proposed mechanisms has resulted and is illustrated by the following summary.

Alkenes on Pt: Bockris, et al.[1], studied the anodic oxidation of several double-bond hydrocarbons on Pt at 80°C. Included were ethylene, propylene, allene, 1-butene, 2-butene, 1,3-butadiene, and benzene. The predominant product was CO_2 with coulombic efficiencies for its production ranging from 60-90% for butadiene and benzene to 100% for ethylene. The kinetic parameters, quite similar for all the compounds, were: Tafel slope = 2(2.3 RT/F), $\partial \log i/\partial pH$ = 0.39 to 0.45, $\partial \log i/\partial \log P_R$ = -0.11 to -0.20, and E_a^* = 19.7 to 23.0 kcal. It was concluded that all the compounds were oxidized by the same mechanism (shown here for ethylene):

$$C_2H_4 = C_2H_4(ads) \qquad (1)$$

$$H_2O \overset{rds}{\rightarrow} OH^{\cdot}(ads) + H^+ + e \qquad (2)$$

$$C_2H_4(ads) + OH^{\cdot}(ads) \rightarrow \ldots \rightarrow CO_2,\ H^+,\ e \qquad (3)$$

The rate equation can be expressed as

$$i = k_2 a_w (1-\theta_T)\exp(\alpha F \nu/RT) \qquad (4)$$

where ν is the potential on the rational scale (vs. the potential of zero charge). Assuming Langmuir-type adsorption, a high surface coverage of the hydrocarbon, and a reported p.z.c.-pH relationship[2], eq. 4 becomes

$$i = k' P_R^{-1/n} a_{H+}^{-0.5} \exp(FV/2RT) \qquad (5)$$

The kinetic parameters of eq. 5 agree quite well with the experimental values.

Ethylene on Au: Several studies have been made on the anodic oxidation of ethylene on Au. In studies by Dahms and Bockris[3] and Kuhn, Wroblowa, and Bockris[4], the catalytic activities of several noble metals and alloys for ethylene oxidation were investigated. The extent of the studies on Au were thus somewhat limited. Johnson, Lai, and James[5] made a separate study of this reaction on Au at 80°C. In acid solutions, their finding supported those of Dahms and Bockris and their proposal of a carbonium-ion mechanism.

$$C_2H_4 = C_2H_4(ads) \qquad (6)$$

$$C_2H_4(ads) = C_2H_4^+(ads) + e \qquad (7)$$

$$C_2H_4^+(ads) + H_2O \overset{rds}{\rightarrow} C_2H_4OH(ads) + H^+ \qquad (8)$$

$$C_2H_4OH(ads) \rightarrow C_2H_4O + H^+ + e \qquad (9)$$

In weakly acidic and basic solutions, a change in the Tafel slope was noted. It was suggested that this resulted from a change in the reaction mechanism. That suggested was similar to the proposal of Kuhn, Wroblowa, and Bockris.

$$C_2H_4 = C_2H_4(ads) \qquad (6)$$

$$C_2H_4(ads) + H_2O \overset{rds}{\rightarrow} C_2H_4OH(ads) + H^+ + e \qquad (10)$$

or

$$C_2H_4(ads) + OH^- \overset{rds}{\rightarrow} C_2H_4OH(ads) + e \qquad (11)$$

$$C_2H_4OH(ads) \rightarrow \overset{H_2O}{\ldots} \rightarrow CO_2,\ H^+,\ e \qquad (12)$$

Acetylene on Pt: The anodic oxidation of acetylene on Pt was studied by Johnson, Wroblowa, and Bockris[6] at 80°C. They found the oxidation to CO_2 to be complete. The kinetic parameters were: Tafel slope = 2.3 RT/F, $\partial \log i/\partial pH$ = 0.8, $\partial i/\partial P_A < 0$, and E_a = 21.5 to 26 kcal. The suggested reaction mechanism was

$$C_2H_2 = C_2H_2(ads) \qquad (13)$$

$$H_2O = OH^{\cdot}(ads) + H^+ + e \qquad (14)$$

$$C_2H_2(ads) + OH^{\cdot}(ads) \overset{rds}{\rightarrow} \overset{H_2O}{\ldots} \rightarrow CO_2,\ H^+,\ e \qquad (15)$$

Acetylene on Au: Johnson, Reed, and James[7] studied the anodic oxidation of acetylene on Au at 80°C. CO_2 production efficiencies varied from 60-80%. A discontinuity found in the Tafel region of the polarization curves in weak acids and bases was interpreted in terms of a change in the reaction mechanism with increasing potential at a given pH. The discontinuity appeared at low c.d.'s in bases and was shifted to higher c.d.'s with decreasing pH. It had disappeared completely in 1N H_2SO_4, apparently shifted outside the Tafel region. The kinetic parameters were: (a) strong acids - Tafel slope = 2(2.3 RT/F), $\partial \log i/\partial pH = 0$, $\partial i/\partial P_A \lesssim 0$, E_a = 19.5 kcal; (b) bases and weak acids (btr)* - Tafel slope =

*Apparent activation energy.

*Below the transition region or discontinuity in the polarization curve.

2(2.3 RT/F), $\partial \log i/\partial pH = 1$, $\partial i/\partial P_A < 0$, $E_a = 19.5$ kcal; and (c) bases and weak acids (atr)* - Tafel slope = 2(2.3 RT/F), $\partial \log i/\partial pH = 1$, $\partial i/\partial P_A > 0$, $E_a = 13$ kcal. The proposed reaction sequences were:

Below the transition region

$$C_2H_2 = C_2H_2(ads) \qquad (16)$$

$$H_2O \overset{rds}{\rightarrow} OH^{\cdot}(ads) + H^+ + e \qquad (17)$$

and

$$OH^- \overset{rds}{\rightarrow} OH(ads) + e \qquad (18)$$

$$C_2H_2(ads) + OH^{\cdot}(ads) \rightarrow \overset{H_2O}{\ldots} \rightarrow CO_2,\ H^+,\ e \qquad (19)$$

Above the transition region

$$C_2H_2 = C_2H_2(ads) \qquad (20)$$

$$C_2H_2(ads) + H_2O \overset{rds}{\rightarrow} C_2H_2OH(ads) + H^+ + e \qquad (21)$$

and

$$C_2H_2(ads) + OH^- \overset{rds}{\rightarrow} C_2H_2OH(ads) + e \qquad (22)$$

$$C_2H_2OH(ads) \rightarrow \overset{H_2O}{\ldots} \rightarrow CO_2,\ H^+,\ e \qquad (23)$$

The pH effect was explained by the participation of H_2O in the reaction in acid solutions where the OH^- concentration was not sufficient to sustain the observed currents.

1-Pentyne on Pt and Au: The anodic oxidation of 1-pentyne on Pt and Au electrodes at 70°C was studied by Danielson.[8] On Pt, the kinetic parameters were: Tafel slope = 2.3RT/F; $\partial \log i/\partial pH < 1$ (acid electrolytes), = 1 (basic electrolytes); $\partial i/\partial P_P < 0$, and E_a = 18-22 kcal. Polymer formation was evidenced by solution darkening and the presence of small floating particles in acid electrolytes. No evidence of polymerization was visible in basic electrolytes. Coulombic efficiencies for CO_2 production were ~ 70%, independent of pH. No significant changes were noted for decreased partial pressures of 1-pentyne. Small amounts of by-products, formaldehyde in acid electrolytes and ethanol in basic, were detected by gas chromatographic analyses.

On Au, studies could not be made in electrolytes with pH ≤ 10.9 due to the formation of an adherent polymer film on the electrode. The film was invisible, but its presence was indicated by apparent passivation and an acquired non-wetting characteristic of the electrode after a short period of polarization. There was no visible evidence of polymerization in the electrolyte. In electrolytes with pH ≥ 11.7, the kinetic parameters were: Tafel slope = 2.3 RT/F, $\partial \log i/\partial pH = 2$, $\partial i/\partial P_P < 0$, and E_a = 22 kcal. Coulombic efficiencies for CO_2 production were ~ 50%. Ethanol and 1-propanol were identified as by-products.

It was possible to correlate the data for 1-pentyne oxidation on Pt and Au with similar reaction sequences. For Pt, the sequence was the same as that proposed previously for acetylene, i.e.,

$$C_5H_8 = C_5H_8(ads) \qquad (24)$$

$$H_2O = OH^{\cdot}(ads) + H^+ + e \qquad (25)$$

or

$$OH^- = OH^{\cdot}(ads) + e \qquad (26)$$

$$C_5H_8(ads) + OH(ads) \overset{rds}{\rightarrow} \ldots \text{ products} \qquad (27)$$

For Au, an additional step was necessary to account for the pH effect of 2,

$$C_5H_8 = C_5H_8(ads) \qquad (28)$$

$$OH^- = OH^{\cdot}(ads) + e \qquad (29)$$

$$C_5H_8(ads) + OH^{\cdot}(ads) = C_5H_8OH(ads) \qquad (30)$$

$$C_5H_8OH(ads) + OH^- \overset{rds}{\rightarrow} \ldots \rightarrow \text{products} \qquad (31)$$

In this latter sequence, the step represented by eq. 29 could also be the equilibrium discharge of water.

1,3-Butadiene on Pt and Au: The anodic oxidation of butadiene on Pt and Au was studied by Agrawal[9] at 70°C. Special precautions were necessary to prevent the butadiene from polymerizing prior to anodic oxidation. The oxidation reaction proceeded without any visible signs of polymerization on Pt in acidic and basic electrolytes and on Au in basic electrolytes. However on Au in acid electrolytes, a polymer formed on the electrode surface that precluded steady-state studies. The coulombic efficiencies for CO_2 production were 85 ± 5% with Pt in acid electrolyte, 92 ± 5% with Pt in basic electrolyte, and 70 ± 10% with Au in basic electrolyte. A trace of a moderately volatile by-product from the oxidation on Pt in acid electrolyte was detected by flame-ionization gas chromatographic analysis. It could not be identified as any of the common oxygen-containing C_1 thru C_4 species.

The majority of the polarization curves for butadiene contains two distinct linear sections with Tafel slopes of ca. 140 and 70 mv in the lower and higher potential regions, respectively. The transition from one section to the other occurred at c.d.'s of about 10^{-4} amp/cm^2 on Pt and 10^{-6} amp/cm^2 on Au. (These are roughly equivalent taking into account a roughness factor of ~ 10^2 for platinized Pt.) The pH effect on current was varied. With Pt at low pH's (0.35 and 1.3), there was almost no effect. At higher pH's, below the transition region, $\partial \log i/\partial pH = 0.5$; above the transition region, $\partial \log i/\partial pH = 1$. With Au in basic electrolytes, $\partial \log i/\partial pH = 1$. Over the pressure range 1 to 10^{-2} atm, the pressure effect ($\partial i/\partial P_B$) with Pt was negative. On Au, it was negative at the higher pressures but became positive as the pressure was reduced below 0.3 atm. Apparent activation energies were about 21-24 kcal, decreasing with increasing potential. No distinct difference was noted between Pt and Au.

A comparison of reaction mechanisms shown above for the oxidation of unsaturated hydrocarbons on Pt and Au shows that none of them completely explain the kinetic parameters observed for butadiene. The primary discrepancies are associated with a seemingly anomalous effect of pH on c.d. and potential. Piersma, et al.[1] resolved this difficulty for ethylene by basing the potential driving force on the rational scale (vs. pzc) rather than the normal hydrogen scale (vs. SHE). The logic of doing this has been recognized and propounded by various investigators, but the characteristics of many reactions and the scope of

*Above the transition region or discontinuity in the polarization curve.

the associated studies have not made it necessary. This possibly may have led to the lengthy assortment of mechanisms that have been used to explain individual cases. The desirability and necessity of using potential driving forces based on a null-value applicable to the electrode under consideration become apparent when one sees that compositional changes in the electrolyte (eg. pH) may affect the pzc and reaction rate in an unequal manner.

Potential of Zero Charge: In the studies reported here, the primary variable affecting the pzc is the pH of the electrolyte. Thus, the pH effects, $\partial \log i/\partial pH$ and $\partial V/\partial pH$, will be affected by shifts of the pzc with pH if one considers the potential driving force for reaction to be

$$\nu = V - V_{pzc} \tag{32}$$

To correlate the experimental results, it is therefore necessary to know the variation of the pzc with pH on both Pt and Au.

On Au, the effect of pH on the pzc has been reported by Andersen, et al.,[10] in the presence of various inorganic anions. In solutions containing non- or slightly adsorbing anions, the relation can be expressed as

$$V_{pzc} = V^{\circ}_{pzc} - \zeta \, pH \tag{33}$$

where

$$\zeta = 0 \text{ (acidic solutions)} \tag{34}$$

$$= 2.3 \, RT/F \text{ (basic solutions)} \tag{35}$$

$$V^{\circ}_{pzc} = 0.14 \text{ V}$$

On Pt, the effect of pH (2.5-11.2) on the pzc for ClO_4 solutions has been reported by Bockris, et al.[11] The relationship is the same as shown in eq. 33 with

$$\zeta = 2.3 \, RT/F \tag{36}$$

$$V^{\circ}_{pzc} = 0.56 \text{ V} \tag{37}$$

In solutions of lower pH, the pretreatment of the Pt electrode is apparently an important consideration if there is opportunity for hydrogen to be dissolved in the metal. As the electrodes used in this study were activated prior to use, the results reported by Frumkin, et al.[11] will be used for solutions with pH < 2.5, i.e.,

$$\zeta = 0 \text{ to } 0.018 \tag{38}$$

$$V^{\circ}_{pzc} = \text{ca. } 0.2 \text{ V} \tag{39}$$

Using these relationships (eqs. 32-39), the kinetic parameters based on the rational potential scale (vs. pzc) for butadiene oxidation were calculated and are shown in Table I. The corresponding values based on the normal hydrogen scale (vs. SHE) are shown for comparison.*

*Note that Tafel slopes ($\partial V/\partial \log i$) and pressure effects ($\partial i/\partial P_B$) are not altered by changing from the normal hydrogen to the rational scale.

Butadiene Mechanism: As mentioned above, none of the various mechanisms proposed previously for the anodic oxidation of unsaturated hydrocarbons were consistent with the kinetic parameters observed for butadiene on both Pt and Au. Similar difficulties were encountered in finding another sequence applicable for both Au and Pt anodes when the rate expression employed potential driving forces based on the normal hydrogen scale. It was possible to resolve these however with the reaction scheme shown below (eqs. 40-43) in conjunction with potential driving forces based on the pzc. This scheme is similar to that used by Piersma, et al.,[1] except that it incorporates water adsorption as a separate step. The sequence is

$$H_2O = H_2O(ads) \tag{40}$$

$$C_4H_6 = C_4H_6(ads) \tag{41}$$

$$C_4H_6(ads) + H_2O(ads) \rightarrow RW^+(ads)^* + e \tag{42}$$

$$RW^+(ads) + H_2O(ads)^{**} \rightarrow \overset{H_2O}{\cdots} \rightarrow CO_2, H^+, e, \text{etc.} \tag{43}$$

The inclusion of the adsorption of butadiene (in some manner) in the reaction sequence (eq. 41) is apparent from both this and other work. The adsorption of water (eq. 40) and its competition with the organic molecules for active surface sites have been discussed by Bockris.[12] The formulation of the remainder of the mechanism (eqs. 42, 43) results from correlating the butadiene data. It will be seen later that this mechanism is also applicable to the anodic oxidation of several other hydrocarbons.

The correlation of the data necessitates some assumptions regarding the mode of adsorption of the reactants butadiene and water on the anode. The initial assumption, which was found to be satisfactory, was the simplest model, Langmuir-type adsorption. This assumption is generally valid only as a limiting condition for either high or low coverages but has been successfully used for the adsorption of several hydrocarbons. Cairns et al.[17], for example, found that propane adsorption on Pt obeyed the Langmuir adsorption rate expression for coverages 0-0.95. This apparently occurred while three different reaction intermediates (ranging from dehydrogenated to partially oxidized propane fragments) were also (proposed as being) present on the electrode surface.

An examination of Table I (both parts a and b) shows that the reaction sequence must yield Tafel slopes of 2(2.3RT/F) and 2.3 RT/F. With Langmuir-type adsorption, these slopes (2.3 RT/αF and 2.3 RT/F) are normally associated with rate determining steps that are the first electron transfer and a chemical reaction following the first electron transfer, respectively. With the usual assumption that α = 0.5, these types of reactions are thus fixed as the rds's for the anodic oxidation of

*RW^+ represents a combined butadiene-water specie that has lost an electron.

**This reacting specie could also be H_2O(sol). The data from this study do not allow such a distinction to be made in this step.

butadiene. If the reaction sequence is to be consistent with the pH effect (Table I b)*, then water discharge (eq. 2) cannot be the first electron transfer step. This would lead to first order H^+ concentration dependencies when the Tafel slope is lowered to 2.3 RT/F, as would also the removal of a hydrogen atom from the butadiene. These considerations lead one to such a sequence as shown in eqs. 40-43. The negative butadiene pressure effect, indicating a high coverage of butadiene and/or the involvement of another unrelated species prior to or during the rds, suggests that H_2O(ads) be included in eq. 42.

The kinetic parameters for Pt anodes (btr) in solutions pH = 0.35-12.5 are $\partial \nu/\partial \log i = 2(2.3\ RT/F)$, $\partial \nu/pH = 0$, $\partial \log i/\partial pH = 0$, and $\partial i/\partial P_B < 0$. These would be consistent with the reaction sequence shown by eqs. 40-42 with eq. 42 as the rds. Considering reactions shown in eqs. 40 and 41 to be in quasi-equilibrium gives:

$$\theta_w = K_w a_w (1-\theta_T) \qquad (44)$$

$$\theta_B = K_B P_B (1-\theta_T)^n \qquad (45)$$

Substituting these in an expression for the current density from eq. 42 gives:

$$i = nFk_{42}\ \theta_B\ \theta_w\ \exp(\alpha F\nu/RT) \qquad (46)$$

$$= nFk' a_w P_B (1-\theta_T)^{n+1}\ \exp\ (\alpha F\nu/RT) \qquad (47)$$

In correlating the butadiene partial pressure data, the parameters for eq. 18 which gave the best fit were n = 4, $K_B = 10^7\ atm^{-1}$ in 1 N H_2SO_4 and n = 8, $K_B = 10^5$ in 1 N KOH.

For Pt anodes (atr) in solution pH = 0.35 to 12.5, the parameters are $\partial \nu/\partial \log i = 2.3\ RT/F$, $\partial \nu/\partial pH = 0$, $\partial \log i/\partial pH = 0$, and $\partial i/\partial P_B < 0$. These fit the sequence of eqs. 40-43 with eq. 43, a chemical combination step, as the rds. This can be visualized as occurring when the increased potential has increased the rate of eq. 42 sufficiently so that the rds is shifted to another step in the sequence. Considering eq. 42 now to also be in quasi-equilibrium gives:

$$\theta_{RW^+} = K_{42}\theta_B\theta_W\ \exp\ (F\nu/RT) \qquad (48)$$

The current density expression from eq. 43 is now

$$i = nFk_{43}\ \theta_{RW^+}\ a_W$$

$$= nFk' a_w^2\ P_B (1-\theta_T)^{n+1}\ \exp(F\nu/RT) \qquad (49)$$

The same values of n and K_B as mentioned above correlated the partial pressure data. The variation of n for acidic and basic solutions found here was also found earlier in studies with C_2H_2 and C_2H_4.[1,6]

For Au anodes in solutions pH 9.9 - 12.5, the parameters are $\partial \nu/\partial \log i = 2.3\ RT/F$, $\partial \nu/\partial pH = 0$, $\partial \log i/\partial pH = 0$, and $\partial i/\partial P_B$ changes from negative to positive values as P_B is decreased from 1 to 0.01 atm. The same reaction sequence (eqs. 40-43) as used for Pt (atr) can also be used here. Values of n = 4 and K_B = 50 were found to correlate the partial pressure observations on Au. This lower value of K_B is consistent with the lesser ability of Au to adsorb hydrocarbons as compared to Pt.[5,7]

*The difficulty in obtaining a sequence consistent with the pH effect based on the NHS was alluded to earlier.

Applicability of the Postulated Butadiene Mechanism to Other Hydrocarbons

1. Acetylene on Pt: The proposed mechanism (eqs. 13-15) gives the current density expression

$$i = k'\ \theta_A (1-\theta_T)\ a_{H^+}^{-1}\ \exp(FV/RT) \qquad (50)$$

With Langmuir-type adsorption, n = 4 and $K_A = 10^4 - 10^6$, and assuming $\theta_T \sim \theta_A$, favorable agreement was found with the experimental partial pressures. These results are the same as for butadiene oxidation on Pt(atr) and thus fit the reaction sequence of eqs. 40-43 with eq. 43 as the rds when the rational potential scale is used.

2. Acetylene on Au: The mechanism proposed for the more acidic electrolytes and btr gives

$$i = nF(k_{17}\ a_w + k_{18}a_{OH^-})(1-\theta_T)\exp(\alpha FV/RT) \qquad (51)$$

The proposed mechanism above the transition gives

$$i = nF(k_{21}\ a_w + k_{22}a_{OH^-})\theta_A\ \exp(\alpha FV/RT) \qquad (52)$$

These equations correlated the experimental data with the assumption of Langmuir-type adsorption, $\theta_T \sim \theta_A$, and n = 4, $K_A = 10^4$ in acid solutions and n = 8, K_A = 2.5 in base.

For the electrolytes of low pH, the kinetic parameters are the same as for butadiene oxidation on Pt (btr). In these solutions, the effect of pH on the pzc is approximately the same ($\zeta \approx 0$) for both Pt and Au. Thus, a reaction sequence as shown in eqs. 40-42 with eq. 42 as the rds can be used to correlate the data and gives the c.d. expression (on the rational scale) shown in eq. 47. Also note that if eq. 51 is transformed to the rational scale using eqs. 32-34 (and remembering that a_{OH^-} is very small in acid solutions), an equation similar in form to eq. 47 results.

In the remainder of the electrolytes, the effects of potential and pH on the current were similar, both above and below the transition region. If one uses the butadiene mechanism for these cases (including Langmuir-type adsorption), the Tafel slopes again determine the sequence in eqs. 40-42 with eq. 42 as the rds. For this sequence, though, on Au and in basic solutions, the pH effect $\partial \log i/\partial pH = 0.5$ (on the NHS) is predicted rather than unity as reported. An examination of the data from Reed's study shows that the experimental effects were 0.75(btr) and 0.85(atr) and were interpreted as being unity. These values might also as reasonably be interpreted as 0.5, which would give agreement between Reed's results and the butadiene mechanism.

3. Alkenes on Pt: The proposed mechanism gives the expression:

$$i = k_2\ (1-\theta_T)\ a_w\ \exp(\alpha F\nu/RT) \qquad (53)$$

(As mentioned previously, potentials based on the rational scale were used in the c.d. equation to explain the observed pH effect.) For Langmuir adsorption conditions and $\theta_R > 0.9$, $(1-\theta_T)$ is proportional to P_R, thus allowing the pressure effect to be correlated. The parameters reported for the alkenes are the same as found in this study for butadiene on Pt(btr) (see Table I) and therefore are also consistent with the reaction sequence shown by eqs. 40-42 with eq. 42 as the rds.

It might be noted at this point that if one looked only at the data for the oxidation of butadiene on Pt from this study, the water discharge mechanism (eqs. 1-3) gives a sufficient correlation. The sequence shown by eqs. 40-43 results when one attempts to expand the correlation to the data for Au using a common sequence.

4. Ethylene on Au: The proposed mechanisms give the rate equations:

In acid solutions

$$i = nFk_8 K_7 a_w \theta_E \exp(FV/RT) \quad (54)$$

In basic solutions

$$i = nF(k_{10} a_w + k_{11} a_{OH^-}) \theta_E \exp(\alpha FV/RT) \quad (55)$$

The ethylene partial pressure effects were correlated using the Langmuir isotherm with $K_E = 1$ and $n = 4$ and 8 for acidic and basic media, respectively.

Again, the butadiene mechanism, eqs. 40-43 with eq. 43 the rds, will fit the case for the acidic electrolytes. Note that here the shift of the pzc on Au is zero (eq. 34). A low adsorption equilibrium constant (K_B in eq. 45) such as reported above gives the observed positive pressure effect.

In the basic electrolytes, the reaction sequence eq. 40-42 with eq. 42 as the rds gives the correct parameters with the possible exception of the pH effect. As with acetylene on Au, $\partial \log i/\partial pH = 0.5$ is predicted while a value of ca. unity was reported. Again a re-examination of the data[5] shows that an empirical value of 0.75 was interpreted as unity. If one should opt to interpret the observed value as 0.5, then all the parameters in basic electrolytes would also agree.

5. 1-Pentyne on Pt and Au: The proposed mechanisms give the following rate equations:

For Pt

$$i = nFk_{27}(K_{25}a_w/a_{H^+} + K_{26}a_{OH^-})(1-\theta_T)\theta_p \exp(FV/RT) \quad (56)$$

For Au

$$i = nFk_{31} K_{30}K_{29} a^2_{OH^-} (1-\theta_T)\theta_p \exp(FV/RT) \quad (57)$$

The reaction on Pt is the same as for butadiene oxidation on Pt(atr) and thus fit the reaction sequence of eqs. 40-43 with eq. 43 as the rds. The same sequence for Au would also be applicable with the additional chemical equilibria preceding the rds.

$$RW^+(ads) + H_2O(ads) = RWOH(ads) + H^+ \quad (58)$$

$$RWO(ads) \overset{rds}{\rightarrow} \overset{H_2O}{\cdots} \rightarrow CO_2, H^+, e, \text{etc.} \quad (59)$$

The ability of the butadiene mechanism to correlate data for other unsaturated hydrocarbons on both Pt and Au as illustrated above lends added credibility to its validity. It also gives further evidence that potentials referred to the null value of the electrode under consideration are the appropriate ones to use in formulating kinetic expressions.

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TABLE I

Summary of Kinetic Parameters for the Anodic Oxidation of Butadiene at 70°C with Potentials based on (a) the Normal Hydrogen Scale and (b) the Rational Scale

Electrode	Electrolyte	(a) Normal Hydrogen Scale (vs. SHE)			
		$\partial V/\partial \log i$	$\partial V/\partial pH$	$\partial \log i/\partial pH$	$\partial i/\partial P_B$
Pt (btr)	strong acids	2(2.3RT/F)	0	0	<0
Pt (atr)	strong acids	2.3RT/F	0	0	<0
Pt (btr)	bases and weak acids	2(2.3RT/F)	-2.3RT/F	0.5	<0
Pt (atr)	bases and weak acids	2.3RT/F	-2.3RT/F	1	<0
Au	bases	2.3RT/F	-2.3RT/F	1	$<0^{*}$ $>0^{**}$
		(b) Rational Scale (vs. pzc)			
		$\partial \nu/\partial \log i$	$\partial \nu/\partial pH$	$\partial \log i/\partial pH$	$\partial i/\partial P_B$
Pt (btr)	strong acids	2(2.3 RT/F)	0	0	<0
Pt (atr)	strong acids	2.3RT/F	0	0	<0
Pt (btr)	bases and weak acids	2(2.3RT/F)	0	0	<0
Pt (atr)	bases and weak acid	2.3RT/F	0	0	<0
Au	bases	2.3RT/F	0	0	$<0^{*}$ $>0^{**}$

$^{*}P_B$ = 0.1 to 1 atm

$^{**}P_B$ = 0.01 to 0.1 atm

ENERGY SAVING PROJECTS RECENTLY COMPLETED AT A LARGE PETROLEUM REFINERY

J. A. Marshall A. D. Kiehne
Shell Oil Company
Wood River, Illinois

ABSTRACT

A significant reduction in energy consumption per barrel of crude oil processed has been effected at Shell Oil's Wood River, Illinois, Refinery during the past two years. Some of the projects which have resulted in reduced energy consumption are:

1. Improved furnace efficiency through closer surveillance and through installation of optimizing controllers on certain furnaces.

2. Lowered reflux-to-feed ratios on certain fractionating columns following reoptimization of operating conditions with current fuel values.

3. Additional heat exchangers purchased and installed on plants originally designed and optimized at lower fuel values.

This paper discusses examples of each of the above projects and the design principles used in developing the projects.

INTRODUCTION

With fuel costs rising and crude oil in short supply, it has become essential for industry to decrease its use of energy. The industrial market uses about 40% of the total energy consumed in the United States today. While only moderate percentage savings are likely to be realized, because of the volume consumed the fuel conserved can still be considerable. Shell Oil Company announced in its 1972 annual report that the goal at Shell's eight refineries was to reduce energy consumption by at least 10% over a period of 2-4 years. This represents a total energy saving by the company of about 3,500,000 barrels per year, which is enough fuel to heat 150,000 homes for an entire St. Louis area heating season.

Fuel costs have risen very rapidly in the past few years. Figure 1 presents the Nelson Cost Index for refinery fuel since 1954, as taken from The Oil and Gas Journal.[1] While the cost was fairly constant during the early part of the period, it has nearly doubled since 1969. The recent rise has been much more rapid than the rise in prices generally, as indicated by the Consumer Price Index[2] which is also plotted in Figure 1 for comparison. Obviously then, saving fuel is becoming increasingly profitable and necessary.

This paper will discuss several of the areas where Shell is reducing fuel consumption at its refinery in Wood River, Illinois. Even though the Wood River Refinery is not new, it has been modernized over the years and is efficient in heat utilization considering its complexity. Nevertheless, the press to conserve energy within the refinery has been a continuing effort. The low relative cost of fuel that was prevalent in the past frequently prevented fuel-saving projects from being attractive. However, with the present higher fuel costs, many projects previously not attractive can now be justified. Since the energy-saving program was announced by Shell in 1972, a reduction in this refinery's fuel consumption of greater than 8% has been achieved.

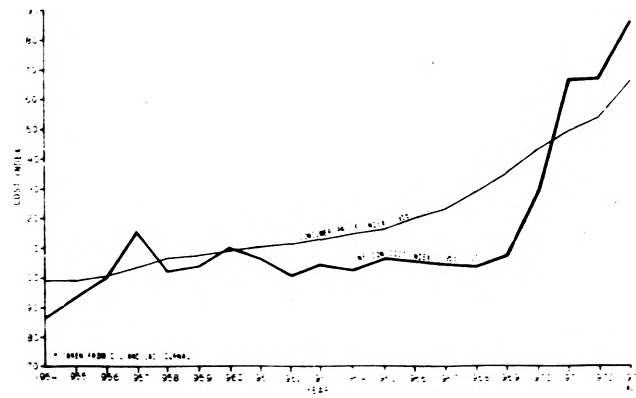

Fig. 1. Nelson Cost Index for refinery fuel.*

ADDITIONAL HEAT EXCHANGERS

One of the more significant ways in which heat economy can be realized in a chemical or petroleum refining process is by returning as much of the heat in the product streams to the feed streams as can be economically justified. As more heat is returned to the process, in general more heat exchange surface is required, and thus the capital cost of the plant is increased. As we have encountered rising fuel costs over the years, we have specified more and more heat exchange surface as each new processing unit has been constructed. An impression of the large amount of heat exchange surface that is being built into newer plants can be obtained from Figure 2. This picture shows the heat exchanger system for our newest crude oil distillation plant constructed at the Wood River Refinery about 5 years ago. As the size of this system suggests, very little heat is wasted in this plant.

A more affirmative indication of the trend toward more heat exchange surface can be seen in Figure 3. This shows how the design approach temperatures, that is, the difference in temperature between hot product streams and cold feed streams, have been lowered on 4 catalytic reformers constructed by Shell during the past 20 years. The first one, constructed in 1955, was designed for a 127°F approach while the most recent one, constructed in 1970, was designed for a 53°F approach. The newer plants are more heat efficient than the older plants. Of course, the capital costs of the newer plants are higher than they would have been if we had designed them to the heat recovery standards of 1955.

One might expect to find a number of opportunities for heat economies in a refinery or chemical plant by examining and reoptimizing the heat exchange systems of older plants using current economic values. Indeed, we have found this to be the case and we have developed a number of projects involving installation of additional heat exchangers on older plants. A typical example is shown in Figure 4. This is a schematic diagram of a lubricating oil vacuum fractionating plant which was constructed at the Wood River Refinery 16 years ago. The plant was designed originally for 13,500 barrels (bbl)/day feed rate, and as shown, some product to feed heat exchange was provided. Feed rate to the plant was later raised to 17,000 bbl/day, however, and the 250 Distillate product side stream draw was increased to twice design flow. As a consequence, its temperature increased 55°F. The product water cooler heat duty increased from 5,800,000 to 13,200,000 Btu/hour, a direct increased heat loss of 7,400,000 Btu/hour.

A design was developed to recover some of the heat wasted in the 250 Distillate water cooler. This is shown in Figure 5. A product to feed heat exchanger for the 250 Distillate stream was added between the two existing bottoms to feed exchangers. This point was selected because of the relative temperature of the hot and cold streams. With this new exchanger, about 7,000,000 of the 13,200,000 Btu/hour which had previously been lost to cooling water were recovered into plant feed, thereby reducing fuel to the furnace. Savings for the project was 13,400 bbl/year fuel oil, after taking into account furnace efficiency and overall plant heat balance. Using a conservative fuel cost of $4/bbl, the new exchanger produces a saving of $53,600/year. Its cost was about $25,000, installed.

Obviously, it was a very attractive undertaking to provide additional heat exchange for the lubricating oil vacuum fractionating plant. This is but one example, however, of quite a number of plants at the Wood River Refinery where new heat exchangers are being installed to recover waste heat. Many more are presently being evaluated as this is clearly an attractive means of saving fuel.

Fig. 2. Heat exchanger system - crude oil dist. plant

Fig. 3. Cat. reformer design approach temperatures

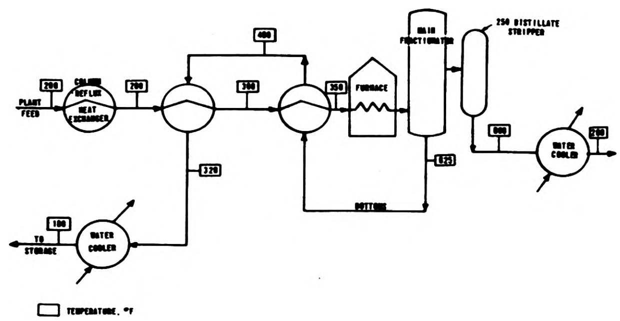

Fig. 4. Luboil vac. fract. plant - as designed.

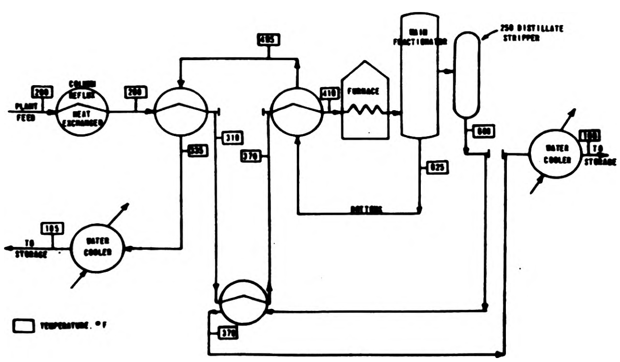

Fig. 5. Luboil vac. fract. plant - revised.

REOPTIMIZATION OF FRACTIONATING COLUMN OPERATION

Reoptimization of fractionating columns is another area attractive for realizing fuel savings. The cost of column operation depends greatly upon the cost of fuel, so certain Wood River Refinery columns optimized in past years at lower fuel values were no longer operating at the economic optimum. It was, therefore, timely to evaluate lower reflux to feed ratios and lower product separation cut points. Such changes can decrease the value of products from the column since lower reflux rates reduce sharpness of separation and lower product separation cut points remove less light material from the heavier products. However, these changes also require less heat input to the column and thereby save fuel.

While there are situations where a change in separation efficiency is unacceptable, in many situations a reduction can be tolerated. When this is the case, reoptimization of a column using current fuel prices will likely be beneficial. The most economical column operation is established at the point where net savings, measured as the difference between fuel savings credit and the lower separation debit, is the greatest. A picture of one column at the Wood River Refinery studied in this fashion is shown in Figure 6 (taller of the two).

This is a column which removes isobutane and normal butane from an alkylation plant product, with an additional sidedraw separation between isobutane and normal butane. The sidedraw, which is primarily normal butane, and the bottoms product are both cooled and routed to storage. The column tops, which is primarily isobutane, is recycled back to the alkylation reaction section.

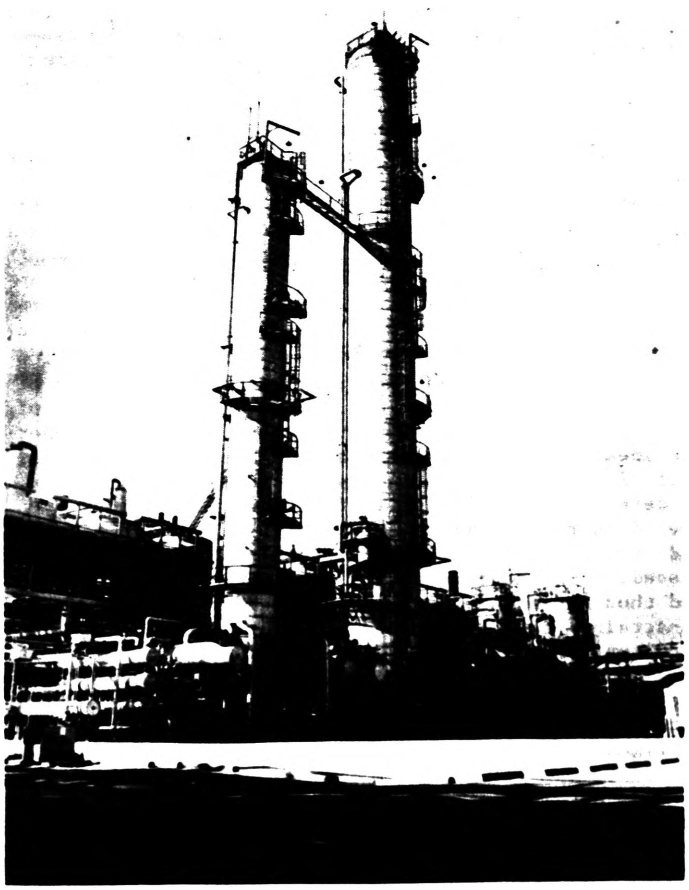

Fig. 6. Alkylation plant deisobutanizer column.

A simplified flow diagram of this system is shown in Figure 7. Normal butane is not desirable in the column tops because it acts as a diluent in the alkylation reaction section. This results in increased acid consumption and lowered alkylate octane number. Value of the column tops is therefore dependent upon its isobutane purity.

At lower fuel costs, this column had been optimized at a reflux to feed ratio of 1.25. The optimization study undertaken recently involved reducing both reboil heat and reflux rate to the column. This lowered fuel costs but decreased column tops value since normal butane in the tops increased due to lower separation sharpness. The economics of this study are presented in Figure 8.

These are plots of column tops isobutane purity versus dollars per day credits and debits. Reflux to feed ratios studied, ranging from 1.25 to 0.78, are shown above the plots. The only credit realized in this optimization was in fuel savings, which is represented by the fuel savings credit plot. A conservative fuel cost of $4/bbl was used. The product value debit plot was constructed using increased cost of operation in the alkylation reaction section. The net savings plot, which is simply the algebraic difference between the other two plots, increases rapidly as reflux rate is initially lowered but then peaks at about $210/day. The optimum range of operation selected was at a reflux to feed ratio corresponding to 88.5 to 89.5%v column tops isobutane purity. This column reoptimization resulted in a net profit of about $70,000/year while saving 40,000 bbl/year of fuel oil.

It was clearly profitable to have undertaken the study of this alkylation plant deisobutanizer column. Other columns at the Wood River Refinery have been reoptimized in this same fashion. In all cases, lower reflux rates or reduced product separation cut points have been profitable due to the higher current cost of fuel.

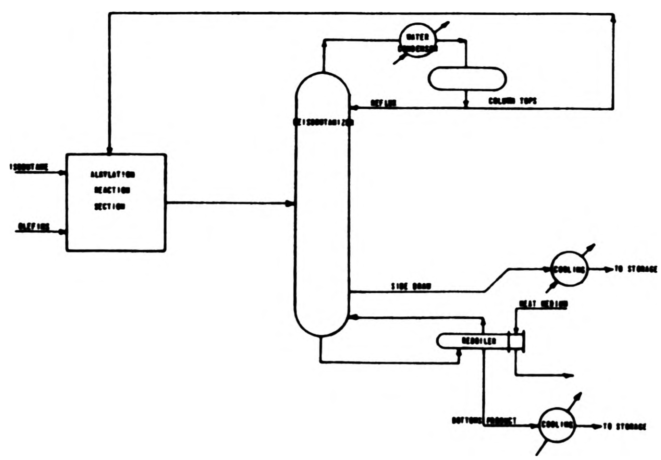

Fig. 7. Alkylation plant deisobutanizer system.

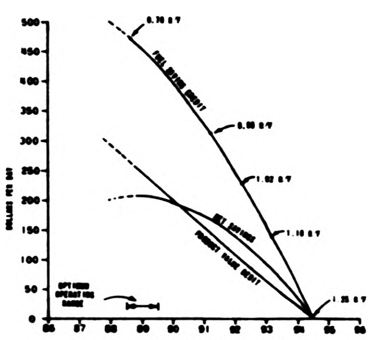

Fig. 8. Reoptimization of alkylation plant DIB col.

IMPROVED FURNACE EFFICIENCY

Fired process furnaces consume about 70% of the total fuel used in Shell refineries. As a result, much effort has been devoted to improvements in furnace efficiency. Potential improvements in this area are both mechanical and operational in nature. One mechanical possibility, for example, is prevention of heat losses by additional maintenance attention to furnace refractory, insulation, and air leakage into the furnace. Another mechanical possibility is installation of additional heat exchanger tubes in the upper part of the furnace just below the stack (convection section) to remove heat from stack gases into a useful service.

The primary operational opportunity of saving fuel in process furnaces is in improved firing techniques. Of course, all firing procedures must be conducted in such a fashion that smoking is prevented. Environmental regulations govern smoke emissions from furnace stacks. The present regulations for the Wood River Refinery require that a general stack opacity (resistance to light transmission) of 40% maximum be maintained. In May, 1975, this will be reduced to 30% maximum.

A large percentage of the fuel used at the Wood River Refinery is heavy residual oil, which is more difficult to fire optimally without smoking than gas. Regardless of the type fuel used, however, the task of firing a furnace is not simple as there are a large number of variables that must be considered. One step which can be taken to improve furnace efficiency from an operating standpoint is to provide adequate surveillance of the firing variables. Reviewing operating personnel in proper firing techniques and encouraging them to give appropriate attention to all firing conditions is very beneficial. Indications are that fuel savings of at least 3% at our refinery have been attained through closer surveillance of furnace operation.

Proper furnace operation requires an adequate supply of air, which enters the combustion chamber primarily via the furnace inlet air plenum and/or air shutters provided for each burner. Some air in excess of the stoichiometric amount is required in the furnace to achieve complete combustion. However, excess air must be kept at a minimum since the unnecessary air absorbs heat that would otherwise be available for heating the process stream. While operating with minimum excess air uses less fuel, it does increase the potential of smoke emissions because changes in operating conditions can quickly result in an air deficiency. Air flow into the furnace is typically controlled by adjusting a damper located in either the inlet air plenum or the furnace stack.

Closer surveillance by operating personnel, while very beneficial, still falls short of yielding optimum furnace operation. Automatic instrument control of the key firing variables is necessary to accomplish this. Shell has developed a ramp-type furnace combustion optimizer for this task. These optimizers can be used while firing either fuel gas or fuel oil. They also have a smoke constraint feature, which is controlled by furnace stack opacity.

The Shell ramp-type furnace combustion optimizer is essentially an excess air control device which operates by controlling damper position. A plot of fuel flow to the furnace and excess air versus damper position for a distilling plant furnace at the Wood River Refinery is shown in Figure 9. As the damper is closed from wide open, excess air in the furnace decreases and fuel usage falls rapidly. When the damper position reaches 25% open in this particular furnace, insufficient air is available for complete fuel combustion and less heat is thus transferred to the process. To try to make up for this deficit in heat, the process variable which controls fuel flow signals for more fuel and fuel usage increases.

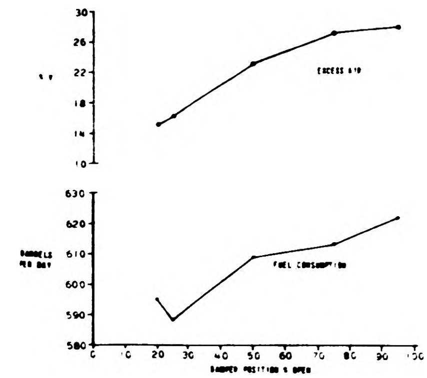

Fig. 9. Dist. furn. - fuel & excess air vs damper pos.

The Shell optimizer operation involves a continual adjustment in damper position with fuel flow as the measured variable. It operates on a change of fuel flow, however, and not on an absolute value of fuel flow. The optimizer strives to close the damper and does so slowly in a linear fashion (ramp) until fuel flow increases as a result of an air deficiency. It detects this increase in fuel flow and ramps open the damper a small amount. Fuel flow then decreases, and the optimizer again moves the damper toward closed. It continues back and forth in this fashion and thus optimizes fuel usage. There is a smoke constraint feature, however, which overrides the fuel flow control signal if necessary and keeps the damper from closing to the point where smoking occurs. The smoke detector is a laser beam opacity monitor, which detects smoke in the stack gas by measuring resistance to light transmission.

A section of the operating record for this optimizer on one of the furnaces at the Wood River Refinery is presented in Figure 10. At Time Zero, the optimizer is put into operation. Before then, the damper was manually set at 47% open with occasional low opacity readings occurring. The damper was quickly brought down to about 25% open, where it was

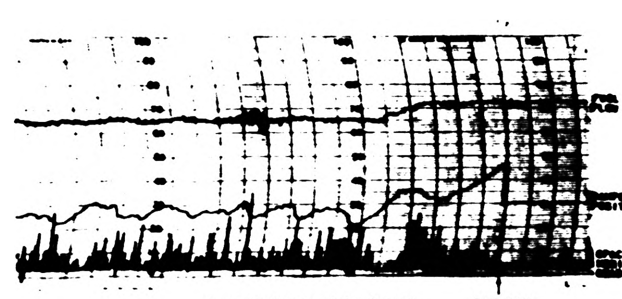

Fig. 10. Shell comb. optimizer record - dist. furn.

controlled over a relatively narrow region. As shown, the opacity readings were higher than for manual control. Since the optimizer continually monitors the stack gas for smoke, it can control the furnace near incipient smoking (minimum excess air) but still effectively prevent undesirable smoke emissions. Fuel usage with the optimizer in service dropped from 72.0 on the operating record to 65.5, or a reduction of about 9%.

It is estimated that this optimizer yields 5-10% fuel savings beyond that realized by closer surveillance alone. Attention by operating personnel is still required, of course, to give attention to aspects of proper firing other than fuel flow, damper position, and smoking. It is important when using this optimizer to insure that uncontrolled air leakage into the combustion chamber has been minimized. If too much air enters the furnace in this fashion, damper control for optimization will not be as effective. Of course, air leakage is never desirable for efficient furnace firing.

One of the distillation plants at the Wood River Refinery has an application in which these optimizers are particularly useful. There are five furnaces in this plant, and the stack gases from each flow into a common stack. If smoke emits from the common stack, it is difficult to tell which furnace is not firing properly. Operating personnel properly tend to be conservative in firing these large furnaces. They would generally operate with more excess air in all the furnaces to insure that smoking doesn't occur, which, of course, leads to reduced firing efficiency. With the Shell optimizer, each furnace can be individually optimized while preventing smoking via a smoke constraint device in its own flue gas.

A Shell optimizer has been installed on one of the furnaces in this plant, and installation on two others is being done. The one which was installed is saving about 7,000 bbl/year fuel oil above that saved by closer surveillance alone. Cost of the optimizer is in the range of $10,000-$15,000.

SUMMARY

This paper has presented three areas in which our refinery is very active in reducing energy consumption. They are not unique to petroleum refining, and the principles can be applied in many process industries. With today's energy shortage, it is essential for industry to conserve energy by the techniques mentioned here or in other fashions. It is also essential that we as citizens do our best in energy conservation at home, in commercial buildings and small businesses, in transportation, and in the general conduct of our everyday living.

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V - MINING AND PETROLEUM

CO-CHAIRMEN:
JOHN P. GOVIER
JAMES J. SCOTT

AN OVERVIEW OF NATURAL GAS SUPPLY AND AVAILABILITY

D. E. Gibbs

Panhandle Eastern Pipe Line Company
Liberal, Kansas

ABSTRACT

Natural gas presently supplies almost one-third of the total U.S. energy supply--and like oil, has had its proven reserves reduced by ever-increasing production. The potential gas reserves of the United States are sufficient to maintain our present demand for a considerable period of time, if these reserves can be found. The exploration necessary has to be financed by increased gas cost. Additional technology will be necessary to increase the amounts of gas that can be produced from our present and future supplies. Several methods of obtaining the capital necessary to perform the additional drilling and areas of technical improvement are discussed.

INTRODUCTION

The present energy crisis has focused attention on all hydrocarbons and has raised questions as to their future availability and supply. This report is an overview of the natural gas supply and availability which will discuss the present supply, the future potential gas supply, a suggestion on how the potential supply can be better developed to the good of our nation, and problems that will face the natural gas industry in reaching the goal of established gas supply.

THE PRESENT NATURAL GAS SUPPLY

The United States, since the early 1930's, has had an ever-increasing need of energy to meet the industrial and domestic demands of its people. Probably the first energy crisis the nation faced many years ago was in whale oil, and Col. Drake's discovery of oil in Pennsylvania relieved the problem and launched the United States on its present course of industrial growth. The present energy crisis has been caused by a large, increasing consumption, which has not been countered by an even greater energy replacement effort. The per capita usage of energy in 1972 was approximately one million BTU's per day. With energy needs on the increase, this average consumption could rise to 1.3 million BTU's per day per person in 20 years; or, stated in an easier measure, a future energy requirement of 9.4 gallons of oil per person per day. In terms of natural gas, this equates to 1,300 SCF per person per day.

The petroleum industry has become the primary instrument necessary to meet this energy requirement. Today, the petroleum industry provides approximately 78% of the total U.S. energy needs. Coal, which has declined in its prorata share over the years, provides about 17% of the total U.S. energy needs. The other forms of energy sources, namely, hydro and nuclear, provide the remaining 5% of the energy. The natural gas industry, which provided 20% of the energy in 1950, now provides 32% of the total U.S. energy requirement. The majority of natural gas is transported by interstate pipeline companies who, in turn, are under direct regulation by the FPC. The remaining gas is transported by intrastate gas companies who are not under the control of the FPC.

The United States' proven gas supply inventory has been declining since 1967, with the exception of 1970 when the Alaskan activity proved successful. At year-end 1972, the remaining recoverable reserves of the U.S., including Alaska, were 266 Trillion cubic feet, as reported by the American Gas Association Reserve Committee. Considerable attention has been placed by the Washington investigators and the news media on the reliability of these reserve estimates. Claims have been placed that the reserves are being kept low to encourage a higher gas price. The majority of the natural gas industry is regulated by the FPC and by law must submit, on an annual basis, reports of all connected gas reserves and the production from the fields. In order to connect new supplies, an interstate company must submit a filing that reports the amount of reserves that a company plans to connect. Additionally, the FPC recently undertook an industry survey to verify by its own engineers and geologists the reserves that are presently connected. This FPC survey found that the reserves, as reported by the AGA, were reasonable--and, if anything, a bit optimistic.

Natural gas, from an environmental standpoint, is the cleanest fuel available. This fact, coupled with the low price, has driven annual production rates upward in an ever-increasing trend. The 1972 annual production was 22.6 Trillion cubic feet. The presently proven reserves would last less than 12 years if we continued at the 1972 depletion rate.

The nation has been producing reserves found during the past 30 years and has been fortunate that the fields had the producing capability of supplying gas as was needed, especially during winter months. The reservoir pressures of these connected fields have been declining due to depletion and we no longer can produce these fields on a peak or demand basis. We do not have the luxury of excess capacity.

Pipeline companies have traditionally produced large volumes in the winter to residential and industrial users, with peak days supplied by storage. The summer production was reduced to industrial usage and storage replenishment. Today, production from the fields is constant during the year; and during those times of peak demand, some customers who have interruptible sales are curtailed. Curtailments in the past two years have become more commonplace due to the nonreplacement of production with new natural gas reserves. Curtailments have also been brought about by insufficient facilities in the field to pump the gas into the pipeline. The Federal Power Commission estimates that from April, 1972, to March, 1974, we will have a total curtailment of 4.3 Trillion cubic feet. This represents roughly 10% of the total production over this same two-year-time period.

THE FUTURE NATIONAL GAS SUPPLY

An industry group, the Potential Gas Agency at Colorado School of Mines, has made projections over the last several years as to the amount of gas reserves that might be found ultimately in the Continental United States, offshore, and Alaska. This committee considers the latest recovery and drilling technology in arriving at its reserve estimate. The latest projection of reserves that are potentially available in the United States as of December 31, 1972, is 1,146 Trillion cubic feet. Of this total, 366 Trillion cubic feet has been attributed to Alaska. The presently proven reserves plus past production at December 31, 1972, for the 48 states, was 667 Trillion cubic feet; therefore, there is a strong possibility of finding additional supplies of gas that are almost twice as great as what we have seen to date. As recovery technology improves, the potential reserves and even the present reserves might be increased.

The current natural gas shortage situation is a case of misoperation of the laws of supply and demand. The federal government created an impossible situation when the "Phillips" decision placed the production of natural gas in a regulated position. By placing price ceilings that do not recognize competitive operations and increased costs, the public was treated to an ideal fuel at an artificially low cost. This created an accelerated demand, but at the same time did not provide an economic incentive to replace.

To replace gas faster than we produce it will require more drilling than the peak drilling year of 1956 when 18 Trillion cubic feet of new gas reserves were discovered. In the last five years, we have added only 20.6 Trillion cubic feet to our natural gas inventory; while, at the same time, we have depleted our reserves by 106.6 Trillion cubic feet.

A stagnation of the United States' petroleum industry has been reflected in the decline of the number of wildcat wells drilled in the last eleven years in the United States. There were 38% less wildcats drilled in 1973 than in 1962. It is encouraging to note, however, that there were more gas wells drilled in 1973 than 1972. A producer presently runs the risk that only one wildcat in eight drilled will be successful in finding hydrocarbons. In addition, the American Association of Petroleum Geologists states that only one in every 60 wildcat wells will find a field containing more than a million barrels of oil or its equivalent in gas. Since it is not known for certain prior to drilling whether one will find oil or gas, the technology, expertise, risks and costs that are involved in drilling for oil are also associated in drilling for gas. In the last ten years, the costs to drill per foot have increased 50%. This price increase does not include the recent increases in pipe costs, which have jumped in some instances as much as 200%. The price received for the wellhead product has increased only 16% for oil and 20% for gas during these same ten years. Gas wells, as a rule, will cost more than oil wells because the gas being found today is deeper than oil.

The demand for gas is being projected to nearly double to 40 Trillion cubic feet per year by 1985. The National Petroleum Council, who has made the prediction used here, estimated that only 30 Trillion cubic feet will be available in 1985, or a deficiency of 10 Trillion cubic feet. The total production includes a projection of only 20.4 Trillion cubic feet from conventional domestic supplies and 9.8 Trillion cubic feet from supplemental gas. The basis of these projections is found in Case Study III of their 1972 report.

SUGGESTIONS TO IMPROVE OUR SUPPLY AND AVAILABILITY

There has to be improvements in the present economical and technical environments of the natural gas industry if our domestic gas supply position is to improve or even hold its own. Like our present oil situation, we cannot allow ourselves to become dependent on a foreign supply. The producing companies that exist today are fully capable of doing the increased exploratory effort. A new producing entity financed through tax dollars does not seem reasonable due to the vast experience, technical knowledge, and number of people that are needed. The incentive to actively search for those reserves, which the Potential Gas Committee and our entire industry believe are there to be found and to increase the amounts of gas, needs to be initiated. Steps that might be taken to accomplish this quest are:

1. Deregulate the wellhead price of new gas. The FPC has attempted in the past several years to allow increases in the amount that an interstate pipeline can pay for new gas; however, the Natural Gas Act and certain court decisions have handicapped the FPC in allowing the higher prices. A competitive market will certainly increase our present exploratory efforts. The burden of paying for this new gas will not hit the consuming public immediately--but over several years.

2. Allow old gas to reach commodity price over a seven-year period, with the differential income applied to drilling. The commodity price would be that price a competitive fuel would bring to the consumer on a BTU or heating basis. It makes sense that the price to boil water or to heat should be competitive regardless of the fuel, if the fuels require the same costs to find and produce. The differential income between the new and old prices should be plowed back into exploratory drilling in the Continental United States. This would assure the using public of a concerted effort to replace the natural gas. The revenue brought in by this legislation would be large, but the capital expenditure necessary to finance the total petroleum industry effort in the next 15 years is gigantic. It is estimated that an additional $1,350 billion will be necessary to finance the capital requirements of industry.

3. Replace cash bonus basis of federal lease sale with royalty payment system. Since 1970, the federal government has received approximately $7 billion from five lease sales of offshore properties. In a recent oil shale lease sale, a total of $210 million, or $41,300 per acre, was paid. Not one cent of this money has been earmarked for helping the energy problem by explorative drilling. The successful bidder for the lease also places considerable economic strain through payment of the bonus even before the first foot of hole is drilled. The government should consider a royalty base of leasing with the successful bidder paying the government out of production. Thus, the government would be guaranteed of income without expense, but would be sharing a gamble with industry. The royalty payments to the government should be earmarked expressly for energy research.

4. A national commitment to energy research should be made. The research of energy should be dealt with on two fronts; creation and utilization. The federal government has already this year earmarked major funds toward nuclear and coal research. The involvement will have to be a continuing effort by both industry and government rather than a one-year shot. The conversion

of energy into work has considerable study remaining. Energy conversion efficiency varies from very low in the creation of light to reasonably high in space heaters. Technical ingenuity will be needed in every phase of this usage spectrum.

5. Improved completion methods will increase the future gas recovered from those fields which are classified as low permeability or "tight" reservoirs. These fields are characterized as having properties that do not allow the gas to flow from the edge of the reservoir to the well bore; hence, the recovery percentage of 20-30 years of productive life might be as low as 30%-40% of the initial gas in place. There are estimated 600 Trillion cubic feet of gas in place in three geological basins of the Rocky Mountains that are considered unrecoverable using present, proven technology. A well completion process called fracturing aids in improving recovery efficiencies. Fracturing creates cracks in the producing formation from the well bore outward, thus providing avenues of production to the well bore. The cracks are created by injecting a fluid under high pressure carrying a proppent to help keep the created fracture open after the injection pressure is reduced. An unfractured gas well in a low permeability reservoir has rates of production that make this well uneconomical even at higher gas prices. If the well can be treated to allow higher production rates, then the project might become economical enough to be sought by a producing company. Improvements are needed in the conventional methods of fracturing in the fluids and the proppents that are used. The most common problem found with the present fluid systems used today is that the injected fluids react unfavorably with the rock that is being fractured. The bad reactions tend to reduce the permeability of the rock rather than improve it. An additional problem is once the crack is created, it will heal with time unless properly propped open.

Another method of creating fractures is by injecting explosive mixtures into the formation and then detonating the mixture. This method has proven very unstable and presently is not being used. Further technology might provide a means of establishing a stable method of handling. A third method of improving the productivity of a formation is through a nuclear device. Projects Gasbuggy, Rulison, and Rio Blanco have proved that the technique of nuclear stimulation can be safely accomplished; however, the flow rates that have been measured are not as high as anticipated. The federal government still has not made any policies concerning the use of atomic devices for development rather than on an experimental basis.

6. Gas fields can be discovered and developed, but before they can become marketable, the gas must be gathered and produced through pipelines. Pipelining has to be considered when making an overview of gas supply. The construction of pipelines has had vast mechanical improvements, but one of the primary construction ingredients is still done by hand--welding. An automatic welding and inspection process should speed up and improve the pipeline construction process.

Consideration should be made toward utilizing a nonmetal pipeline that can be constructed on site without joints. The new innovations in epoxies and plastics should find application in areas where high pressure pipelines have traditionally been steel. The petroleum industry today is facing a tubular goods shortage and it should be expected that this same shortage would be carried over to the pipeline groups.

Pipeline laying problems in difficult surroundings, i.e., Arctic and offshore, have and will continue to plague any attempts for quick connections to main gathering systems. Over 34% of the potential gas to be found is located either in Alaska or in water depths greater than 600 feet. Development research in these two areas will have to continue if we are to market the gas that will be found.

7. The majority of the major pipeline companies today should continue increased programs to investigate and experiment in fields of supplemental gas supply. Coal gasification has probably received the greatest attention due to it being a domestic supply alternative. LNG depends on foreign supply, and in the absence of additional U.S. gas supply, this form of energy acquisition must be exploited. The impact of all supplemental gas on our total gas supply, as projected by the National Petroleum Council, however, is minor in 1975 and only slightly over 20% in 1980.

PROBLEMS IN OBTAINING IMPROVEMENT

The public image of the gas industry has been influenced by the present energy shortage--and particularly the oil shortage. Whereas the oil industry obtains large quantities of fuel from foreign sources, the gas industry does not, but relies almost totally on domestic supply. As pointed out previously, the same technology, engineering, and drilling procedures are used to find oil and gas. The economic incentive to search for oil has been lacking, and it should be reasonable that a search for a product that a producer can receive even less money for on a commodity basis would not be sought. The American public who uses gas or who uses electricity produced from gas-fired systems will not want to pay higher prices for their fuel. To find new gas, the price of new gas has to go up to provide the capital necessary for finance. Pipeline companies who are regulated as to their rate of return cannot make windfall profits. The producers who receive a higher price for their gas will need the additional capital to continue in the drilling and exploration business. The competition for leases will increase and the landowner will benefit from higher lease costs, who in turn will pay higher taxes. The selling of this logic to government and customers is our largest task.

The second problem that must be faced is time of development. A new prospect is not worked and developed overnight. It takes years to wildcat, develop, and build a pipeline to gather gas. The industry also finds that the natural gas often has to be treated prior to being pipeline quality. Treatment plants are not shelf items at the hardware store.

Our present gathering systems are producing from fields whose pressures are declining due to heavy production demands. Compression requirements in the field are going to start climbing at an alarming rate. The supply of these compressors might become critical if steel shortages develop.

SUMMARY

The need to develop additional gas reserves has no arguments from those who presently use natural gas as a fuel. The present escalating demand for this fuel cannot be met from presently known supplies. The likelihood of finding additional gas through exploration and new recovery processes is excellent if proper price incentive can be established.

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BELLAMY FIELD TESTS: RECOVERY OF MEDIUM GRAVITY CRUDE OIL FROM MISSOURI TAR SANDS BY COUNTERFLOW UNDERGROUND BURNING

by J.C. Trantham, Phillips Petroleum Co.

In the current energy shortage, the heavy oil and tar sands of the United States are assuming critical importance. This is true for at least two reasons: first, they constitute a major resource, amounting to some 150 billion barrels in place; and second, their whereabouts is known--exploration will not contribute to the lead time required for bringing these resources into the national energy picture. Moreover, many of the technological problems have been solved. The delay in producing these heavy oil and tar deposits is due primarily to economics.

Figure 1. shows the location of known deposits of heavy oil and tar sands of the United States. For the purpose of this paper, the definition of Dietzman et al in their Bureau of Mines information Circular 8263, has been adopted. Oils of API gravity less than 25° are referred to as heavy oils. The further distinction is made that any "oil" which permits no significant commercial production at its natural reservoir temperature will be called a "tar", or more correctly a bitumen.

The locations shown on the map represent more than 2,000 reservoirs in over 1,500 fields in 26 states. These deposits have, to a large extent, lain dormant for many years. With the exception of production of relatively small percentages of the oil in place from some of those with higher gravity oils, e.g., 15°-25° API, there was little interest in these fields because costs of production exceeded the costs of finding and producing "new oil" at home or abroad. In the 1950's and the 60's, however, as the costs of finding "new oil" began to move towards the chronically depressed price of domestic crude oil, interest began to awaken and laboratory and field experiments were performed in many heavy oil and tar deposits. Thermal methods such as steam or hot water injection and in situ combustion were the chief processes tested. A large flurry of activity in the mid-60's resulted in technically feasible but still, for the most part, uneconomic recovery of these resources. Activity subsided while petroleum supply and demand moved inexorably toward the long predicted shortage of energy the nation is experiencing today.

The period of high activity in the 60's was important, however. During this period much of the technology of recovery of oil from these resources was worked out, providing a head start, in this respect, on solving today's energy problems.

During the period from 1955-58, Phillips Petroleum Company was active in the search for techniques of recovering the important raw materials discussed above, with emphasis on tar sands of the type found in Western Missouri. This paper reviews the series of field experiments performed near Bellamy, Vernon County, Missouri, about 50 miles north of Joplin, during that period.

CHOICE OF PROCESS

Early in 1955 Phillips Petroleum Company began preparations to field test counterflow underground combustion for producing oil from bituminous sands. At that time, all published information on in situ combustion dealt with direct drive (forward) combustion in which the combustion front moved in the same direction as the injected air stream as shown in Case A. Figure 2. Our laboratory research had shown that direct burning was not applicable to tar sands because the heat-thinned native hydrocarbon congeals in the cold rock ahead of the fire front, forming a gas permeability block which prevents further gas (air) flow and the fire goes out. Our laboratory work showed that the counterflow process eliminated this problem. It will be noted that in the counterflow process the ignition is conducted in the producing well and the fire burns towards its source of air. Its unique principle which makes it applicable to tar sands is that all the heat-thinned hydrocarbon must pass through the fire zone and hot rock. This causes thermal cracking to take place and the resulting oil is much lighter than the parent tar, being so physically and chemically changed that it passes through the rock as a vapor and low viscosity oil. The producing wells behave as high temperature gas condensate wells. Of course, when the fire front has moved a considerable distance from the producing well and the rock has cooled to some extent, more oil condenses; but this is never serious because the original tar has been permanently changed to a medium gravity oil containing very little heavy ends. A more detailed discussion of the composition of the produced oil will be given later. Some other interesting aspects of the counterflow combustion process will also be discussed later in the context of the field response to the process.

LOCATION OF FIELD TEST SITE

In choosing a test site for the process, the objective was to find a reservoir with adequate tar content and permeability, isolation from barren zones, thin enough to require modest compressor capacity, and shallow enough to permit the drilling of large numbers of wells at relatively low cost. One further requirement was that the site be within a few hours drive of Phillips Bartlesville laboratories.

Exploratory coring led to a location near Bellamy, Vernon County, Missouri. This site, located about 50 miles north of Joplin possessed all the attributes sought for the series of experiments.

Table 1. shows the characteristics of the test reservoir. The tar sand was a Bartlesville sand, 12 feet thick, extending from 49 to 61 feet subsurface, with shale

and siltstone laminations sealing the top and the bottom. The 12-foot zone was part of a larger 30-foot thick tar sand interval which extended both above and below the test zone. The 12-foot zone was further subdivided into two approximately equal layers, the lower being more permeable than the upper. The line drive test which is the chief subject of this paper was conducted in the lower 6-foot zone, with the upper considered as part of the 55-foot overburden. In other tests, the full 12-foot interval was used.

Figure 3. shows the arrangement of facilities and well patterns used in the tests. In all, seven different patterns were used, including 5 spots, a 7-spot, a 10-well radial pattern, and a 15-well line drive. Since the latter most closely resembles what is considered the preferred configuration for commercial application, this paper will concentrate on the line drive experiment. However, many of the conclusions reached are based on experiments which preceded or followed this test.

The line drive pattern, Figure 4., consisted of a 5-well line of producers flanked by two 5-well injection lines. Spacing between wells was 5 feet and between lines, 15 feet. The two end wells in each line served as guard wells, while the middle three wells constituted the true line-drive elements. Twenty observation wells were interspersed among the injection and production wells to provide close-spaced horizontal and vertical subsurface temperature profiles, and thus permit accurate measurements of the rate of propagation of the burning front.

WELL COMPLETIONS

Only the main air injection wells and the producing wells were cased. For most of these, the hole was drilled to the top of the pay zone, the casing was set, and a smaller open hole was drilled on through the pay. Instrument wells and some auxiliary air injection wells were drilled directly to pay bottom, packed through the pay zone with gravel or tar sand, and then cemented to ground surface with no casing.

Figure 5. shows a diagram of the completion of a producing well equipped for ignition. The function of the fuel pack, thermocouple, and water injection systems will be discussed later. Other aspects are self-explanatory. The instrument well completion is likewise self-explanatory. Figure 6. An important point which should be made, however, is that there should be provision for removing water, since these wells invariably fill with water and serve as excellent devices for measuring the temperature of boiling water under indeterminate pressures near atmospheric.

SURFACE FACILITIES

A flow diagram for the line drive test is shown in Figure 7. The injection system was arranged so that air, propane, or a premix of these two gases could be injected into either the injection or the production wells. Orifice runs, located at each injection well, were found to be the most reliable method of measuring injected gas volumes. Air compressors capable of delivering a total of 1.2 million scf/D at 100 psig were used for the line drive test.

The most important features of the recovery system were the sand trap, to knock out entrained sand in the early stages of a test, and the separate condensation of the heavy and light fractions of the produced fluid stream. The sand trap was a simple impingement type made of steel pipe designed to be emptied by simply opening a gate valve at the bottom. The air condenser was a series of parallel pipes which were cooled sufficiently by the wind to condense the heaviest fraction without condensing the water. The water-cooled condenser converted the water and lighter organic components to an easily separated two-phase liquid product. No effort was made to capture low boiling components such as butanes and lower molecular weight compounds; and, as will be seen later, the product contained very little of such components.

A small stream of produced gas was piped to the instrument building for analysis.

INSTRUMENTATION

Standard methods of measurement were used to monitor the temperature, pressure, and flow rate of the injected air (or propane air premix) as well as the product stream. For control purposes, the oxygen and carbon dioxide contents of the exhaust gas were continuously recorded, using a Beckman magnetic susceptibility oxygen analyzer and a specially designed carbon dioxide analyzer, based on a thermal conductivity cell. These were supplemented in the field by Orsat analysis of gas. Oil and water samples were taken routinely for examination at the Phillips Research Center in Bartlesville, Oklahoma.

OPERATION

<u>Preliminary Reservoir Conditioning</u>

The first step in each experiment was to inject air into the wells, which would subsequently be ignited, until an air bubble had expanded to encompass the sand volume within the pattern. This was necessary because the tar sands were completely saturated with water and immobile tar. The expelled water was not produced, but was pushed back outside the pattern where it helped to confine injected air to the pattern. This phase of a test was referred to as the dry-out period and required about two weeks for the line drive experiment.

Analysis of the very first air which passed through the virgin formation revealed that it had been stripped of a major portion of its oxygen at the prevailing reservoir temperature of about 55° F. There was no detectable temperature rise in the rock adjacent to the injection well, but the presence of small amounts of CO_2 and CO in the exhaust air indicated that a very slow oxidation was occurring. The capacity of the tar sand to absorb oxygen decreased rapidly as additional air passed through it, with produced air averaging about 21 percent oxygen after injection of air equivalent to about 800 scf/bbl of tar in place in the various test pattern areas.

Injection pressures were limited to 50 psig to avoid pressure parting of the overburden which occurred between 55 and 60 psig when flowing offset wells were shut in or when simultaneous injection was in progress in a group of wells with no intervening producers.

Ignition

Several ignition techniques were tested. These included electric and gas-fired heating devices and combustible well-bore ignition packs. Once the basic principles of counterflow combustion ignition were understood, we were able to ignite at least a portion of the test zone with any of these methods. The obvious method of igniting by direct drive and reversing the air flow did not work. When it was attempted, the formation became tar blocked a short distance into the formation within a matter of minutes, and air could neither be injected into, nor produced from, the formation.

The best method consisted of packing the pay interval with about 50 lbs of diesel oil saturated charcoal briquettes (about 20% diesel by wt.) as shown in Figure 5. Combustion of the ignition charge was started by dropping a burning railroad warning fusee down the production tubing through the lubricator while the well was temporarily shut in. The well was then opened gradually with the exhaust stream vented to the atmosphere until well bore thermocouples and smoke production showed that the fuel pack was burning briskly. At this point about 1 percent propane was premixed with the input air at the injection wells. After 26 hours, when the thermocouples in the nearest observation wells showed the entire 6-foot pay interval had been ignited and the fire front was moving out into the formation, the production stream was passed through the surface recovery system. As soon as this operating condition was established, the bottom hole temperature was maintained between 500° F. and 900° F. by injection of metered amounts of water. This water was deducted from total produced water to obtain the true water production from the oil recovery process.

During the nine days of continuous, controlled operation of the line drive experiment, the production from the three true line drive producers was put through the recovery system, while the two flanking producers were vented. This gave a more realistic value to the observed production data by reducing edge effects. The line drive test ended with the combustion front about 1 foot from the west line of injectors (Figure 4.) when thermally induced fractures extended into the injection wells resulting in air breakthrough. This ended the test.

Line Drive Performance

Table 2. shows oil, water, and gas production rates from the true line drive segment of the pattern for stabilized measurement intervals. The air-oil ratio given is the volume of dry air that would have to pass through the fire zone to produce a barrel of water-free oil. It is interesting that the injection of 1 percent propane in the air resulted in a decrease of 5,000 scf/bbl in the air-oil ratio under these particular operating conditions, but had no measurable effect on the maximum combustion temperature or fire front propagation rate.

Produced WOR's, excluding well bore cooling water, ranged from 1.5 to 2.0 with an overall average of 1.7. A WOR of about 1.0 could be accounted for by the combustion reaction itself; the balance appeared to be residual formation water.

When the line drive test was shut down due to thermal fractures as the fire front advanced to within one foot of the west line of injection wells, about 83 percent of the line drive segment was burned over. Calculations show that with similar behavior in a pattern with ten times the well spacing of the line drive test about 98 or 99 percent would have been burned. Temperature profiles and postmortem coring showed that the vertical sweep efficiency was 100 percent within the line drive burned out area. The recovery factor for the test was 67 percent of the volume of tar originally in place. Of this, 60 percent is actual recovery, while 7 percent is due to increase in volume as the tar is converted from 10° API tar to 26° API oil.

COUNTERFLOW COMBUSTION PROCESS CHARACTERISTICS

The important relationship between fire front propagation velocity and average formation air flux under Bellamy field conditions is illustrated in Figure 8. which combines the line drive data with the data from a subsequent radial drive test performed in the same 6-foot sand interval. The propagation velocity falls sharply toward zero as the average formation air flux approaches 19 scf/hr-sq ft.

This air flux is regarded as the critical limiting flux for the particular sand zone under test--that is, it represents the air velocity below which the counterflow front would echo, or burn back along its own trajectory by feeding on the residual carbon deposited in its original wake. Figure 9 shows one example of the thermal echoes observed during certain Bellamy field tests in which the formation air flux rate dropped below its critical limiting value. In this example, the original counterflow front passed by a monitor well at the 100-hour mark with the echo, or burn-back, returning at 200 hours.

The curve defined by the empirical equation $vf = 0.013 (u_a - 19)^{½}$, where vf is the fire front propagation velocity and u_a the air flux, gives a good fit with the Bellamy field data as shown in Figure 8. A similar square root dependence of v_f on u_a with different numerical constants for systems having different heat loss factors has been observed to describe a variety of bench scale counterflow burning experiments conducted in Phillips' laboratories.

Since the preceding equation predicts that v_f will approach zero as u_a approaches 19 scf/hr-sq ft, the observed Bellamy air--oil ratios should approach infinity at these lower u_a values. This is confirmed by field measurements of produced (equivalent) air--oil ratios vs u_a. Figure 10. shows that the air--oil ratio is observed to trend toward very large values as u_a approaches 19 scf/hr-sq ft. These field data, in combination with theoretical predictions (dashed line) developed for the limiting case of zero heat loss, also suggest that there may be a broad minimum in the Bellamy air-oil ratio vs u_a curve in the vicinity of 40 scf/hr-sq ft.

Maximum temperatures measured in the observation wells ranged from 850 to over 1,600 F., depending on the air flux and other conditions. Low values were obtained at the lower air fluxes when air alone was being injected, while high results were observed in special tests during the injection of air enriched with oxygen. In general, however, the temperature maxima lay between 900 and 1,100 F. with both air and air-plus-propane premix for this reservoir situation.

In general, it was found that the air transmissibility of the Bellamy test sand underwent an increase of about 20-fold as the counterflow combustion zone passed through it. Postmortem coring after several of the experiments showed this was due mostly to extensive thermal fracturing on a local scale. This phenomenon was so reproducible that in the later tests of the Bellamy series it was taken into account in designing test pattern well spacings.

CHARACTERISTICS OF PRODUCED FLUIDS

One of the most intriguing aspects of counterflow combustion is the nature of the oil produced. Whereas direct drive combustion produces oil of gravity which may be 1^o or 2^o API above that of the oil in place, the counterflow process, with the cracking which occurs, upgrades the native material to a remarkable degree. Table 3. shows that the original 10^o API, 500,000 cp tar is converted into a 26^o API, 10 cp oil. ASTM distillation shows that 94 percent boils between 450^o and 950^oF. with only 3.3 percent in the gasoline and 2.7 percent in the 950^+ residue ranges.

Some additional qualities of counterflow combustion oil are the reduced sulfur and nitrogen, about half the amounts in the native tar. In addition, laboratory combustion experiments showed that on oils of high nickel and vanadium content, these elements were reduced from 97 ppm to 2 ppm and from 311 ppm to 1 ppm for NiO and V_2O_5, respectively. Nickel and vanadium are troublemakers in crude oil refining.

A note of caution should be sounded on the reduction in sulfur and nitrogen since these components may appear, along with carbon monoxide, as air pollution agents. Sulfur in the oil is converted into sulfur dioxide, carbonyl sulfide, and carbon disulfide. No nitrogen compounds have been detected in the exhaust gas, and it is possible that the nitrogen lost by the oil may have been ultimately converted to molecular nitrogen whrch would not be detectable in the 80 percent nitrogen exhaust gas. Table 4. shows some typical exhaust gas analyses minus the sulfur compounds referred to previously. In these particular analyses, these compounds were not determined and the data were normalized. Our laboratory experiments have shown that these sulfur compounds were usually present to the extent of about 500 to 1,000 ppm.

A typical water analysis is shown in Table 5. Since the water native to the reservoir was fresh and combustion-produced water would contain no inorganic dissolved solids, it is not surprising that the total solids content was as low as it was. The high iron and aluminum content was probably due to the reaction of the pH 3 water with iron and aluminum present in the sand. In spite of the low pH, there was no evidence of appreciable corrosion of the black iron pipe used in most of the experiments.

The reaction in the reservoir led to the formation of several types of oxygen-containing water-soluble organic compounds. Note particularly the presence of 2,550 ppm of carboxylic acids, expressed as acetic acid. One particular acid, benzoic, has been isolated as pure white crystals from the produced oil and, being somewhat water soluble, is evidently present in the aqueous phase as well.

CONCLUSION

In the foregoing discussion, a technically feasible approach to in situ recovery of oil from immobile tar contained in sands typified by those of Western Missouri has been demonstrated. There remain two basic impediments to widespread application of this technique. One of these is technical; the other, economic. The technical difficulty lies in the tendency of many tars and heavy oils, particularly in warmer (deeper) reservoirs to undergo spontaneous ignition.

Thus, air injection may ultimately set up a direct drive combustion front which prevents counterflow combustion from being accomplished. Some oils have a much stronger tendency to do this than others; but in all cases, it is aggravated by elevated temperatures and pressures. Our success in the Bellamy project was probably due to a combination of a low reactivity tar and a low reservoir temperature and pressure. In any prospective counterflow combustion project, careful testing of the reservoir is required before large investments are committed.

The economic problem is obvious. In any combustion recovery method, the investments are high and are generally front-end loaded, the return being deferred for a period of time after large investments are made. This is less true of counterflow than of direct drive combustion since production begins soon after ignition in counterflow combustion. The most important point is that no currently available technique can bring the important resources of the United States tar sands into our energy picture at prices which were common a few months ago. Recent substantial advances in domestic crude oil prices have rekindled interest in widely known U.S. heavy oil and tar deposits. A price roll-back or other punitive legislation by government in response to a hysterical public could place these energy sources beyond our reach for many years. If the American people can be made to understand that cheap energy for wasteful use is no longer available and that the only real solution is to allow the American economy to operate, sources of energy such as the Missouri tar sands will be brought into the picture.

TABLE 1

BELLAMY FIELD TEST

TEST RESERVOIR PROPERTIES

TEST	UPPER ZONE	LOWER ZONE*
EFFECTIVE AIR PERMEABILITY, WITH TAR PLUS RESIDUAL WATER IN PLACE	106 MD	266 MD
ABSOLUTE AIR PERMEABILITY, TAR AND RESIDUAL WATER EXTRACTED	229 MD	814 MD
FRACTIONAL POROSITY	0.247	0.255
TAR SATURATION	0.508	0.412
INITIAL WATER SATURATION	0.492	0.588
RESIDUAL WATER SATURATION	0.150	0.100
TAR CONCENTRATION, BBLS/A'	974	813
INITIAL GAS SATURATION	NIL	NIL
PAY THICKNESS, FT	6.0	6.0

* AS EMPLOYED IN THE LINE DRIVE TEST.

TABLE 2

BELLAMY FIELD TEST

LINE DRIVE PRODUCTION DATA

TEST NO.	DATA INTERVAL (HOURS)	PREMIX (C_3 %)	DRY OIL (BOPD)	TOTAL WATER (BWPD)	EXHAUST GAS, AS DRY AIR (MCF/D)	AOR (MCF/BBL)
1	9	NIL	3.8	5.6	173	45.5
2	8	NIL	3.8	6.7	162	42.7
3	8	NIL	3.7	7.3	164	44.4
4	8	1.0	4.6	6.1	170	37.0
5	24	1.0	4.8	6.3	187	38.9
6	16	1.0	4.6	7.2	186	40.4
AVG.	25	NIL	3.8	6.5	166	43.7
AVG.	48	1.0	4.7	6.5	182	38.7

TABLE 3

BELLAMY FIELD TEST

COMPARISON BETWEEN PRODUCED OIL AND ORIGINAL TAR

	TYPICAL COMPOSITE FIELD TEST OIL	ORIGINAL TAR IN PLACE
DISTILLATION, (VOL. %)		
IBP-400 F	3.3	NIL
450-650 F	61.4	10
650-900 F	32.6	26
900+ F RESIDUE	2.7	64
PHYSICAL PROPERTIES		
GRAVITY, °API	26	10
VISCOSITY, CP AT 75 F	10	500,000
POUR POINT, °F	--20	
COMPOSITION		
CARBON	84.7 WT. %	86.7 WT. %
HYDROGEN	12.3 WT. %	10.3 WT. %
OXYGEN	1.9 WT. %	1.4 WT. %
SULFUR	0.14 WT. %	0.75 WT. %
NITROGEN	0.02 WT. %	0.1 WT. %
OLEFINS	21 WT. %	
AROMATICS	18 WT. %	
MOL WEIGHT	270	651

TABLE 4

MISSOURI FIELD TEST

TYPICAL EXHAUST GAS ANALYSIS

COMPONENT	TEST NO. 1	TEST NO. 2	TEST NO. 3	TEST NO. 4
H_2 MOL. %	0.7	0.4	0.4	0.9
N_2 MOL. %	80.7	80.8	81.0	80.4
CO MOL. %	1.9	1.6	2.0	2.3
A MOL. %	0.9	0.9	0.9	1.0
CO_2 MOL. %	14.1	12.5	13.7	14.0
O_2 MOL. %	1.0	3.2	1.5	1.0
CH_4 MOL. %	0.4	0.2	0.4	0.3
C_2H_6 MOL. %	0.1	0.2	0.1	0.1
C_2H_4 MOL. %	–	–	–	–
C_3H_8 MOL. %	0.2	0.3	–	–

TABLE 5

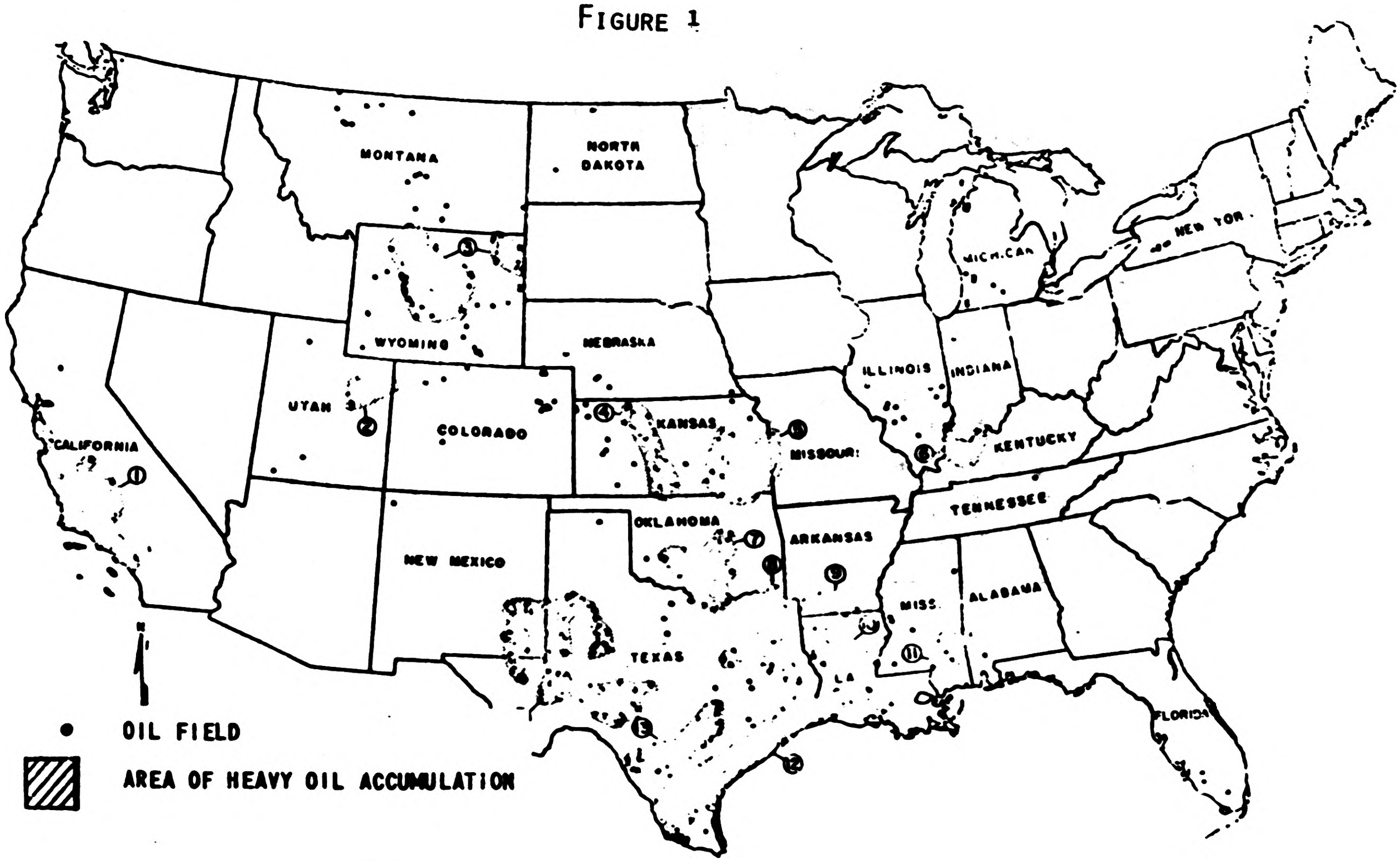
BELLAMY FIELD TEST

LINE DRIVE OPERATION
TYPICAL PRODUCED WATER ANALYSIS

INORGANIC MATTER	PPM
SILICA	26
SODIUM AND POTASSIUM	0
IRON AND ALUMINUM	721
CALCIUM	29
MAGNESIUM	8
CHLORIDES	184
SULFATES	412
BICARBONATES	0
TOTAL INORGANIC SOLIDS	1,060

ORGANIC MATTER	PPM
ALCOHOLS, AS METHANOL	35
CARBONYLS, AS ACETONE	5
PHENOLS, AS PHENOL	230
CARBOXYLIC ACIDS, AS ACETIC ACID	2,550

FIGURE 1



GEOGRAPHICAL LOCATION OF HEAVY OIL FIELDS IN THE UNITED STATES
(FROM DIETZMAN, ET AL, U.S.B.M. I.C. 8263)

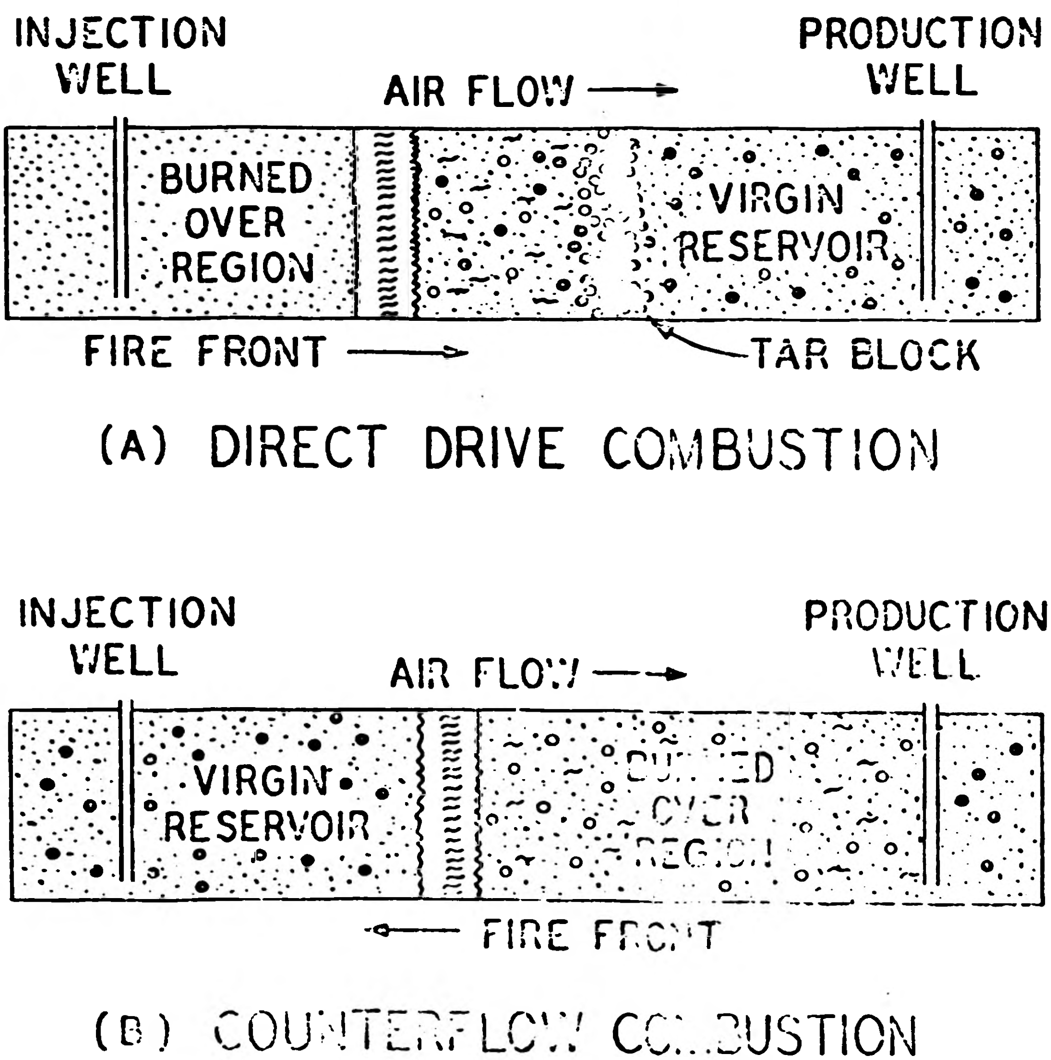
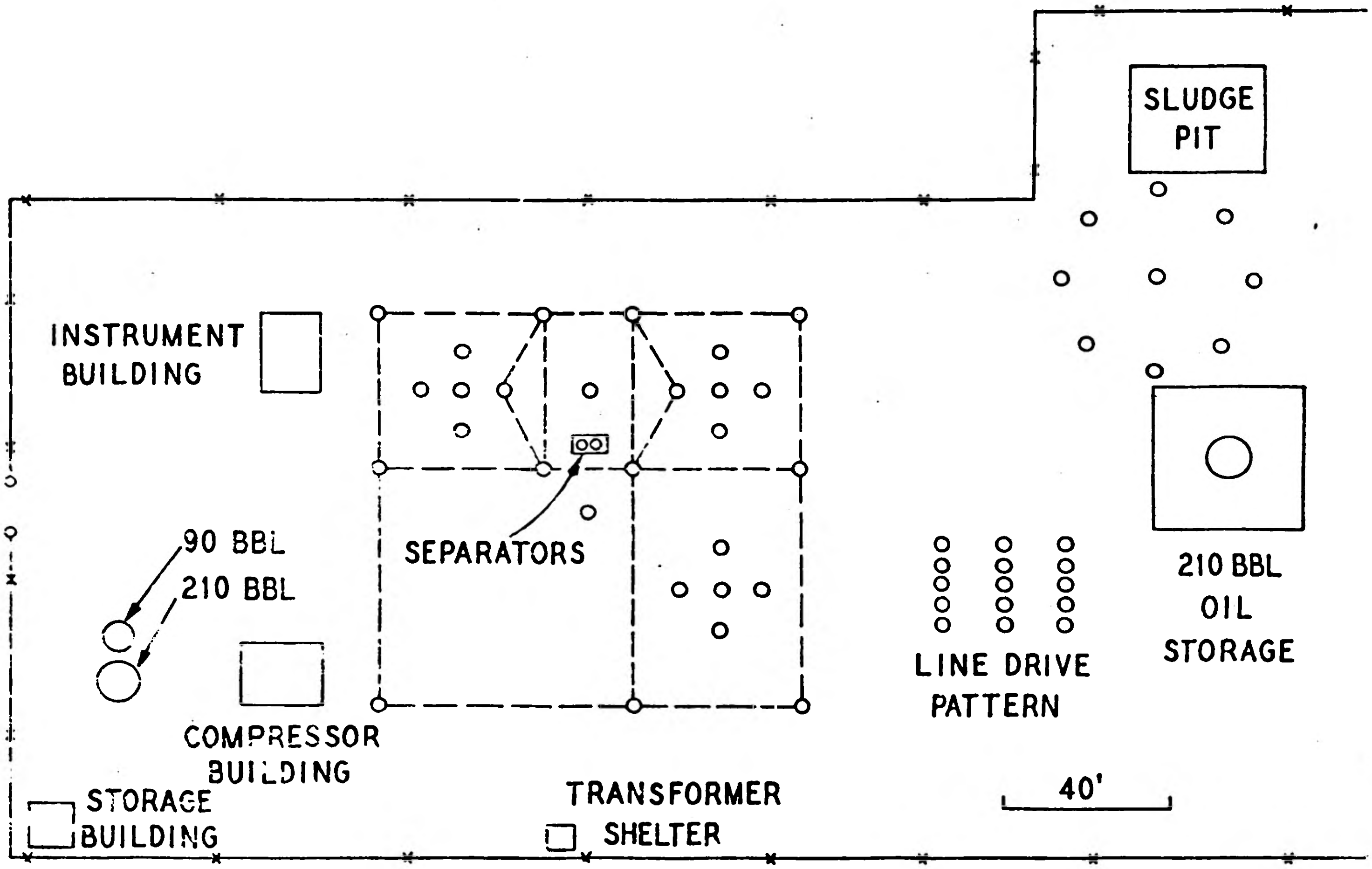
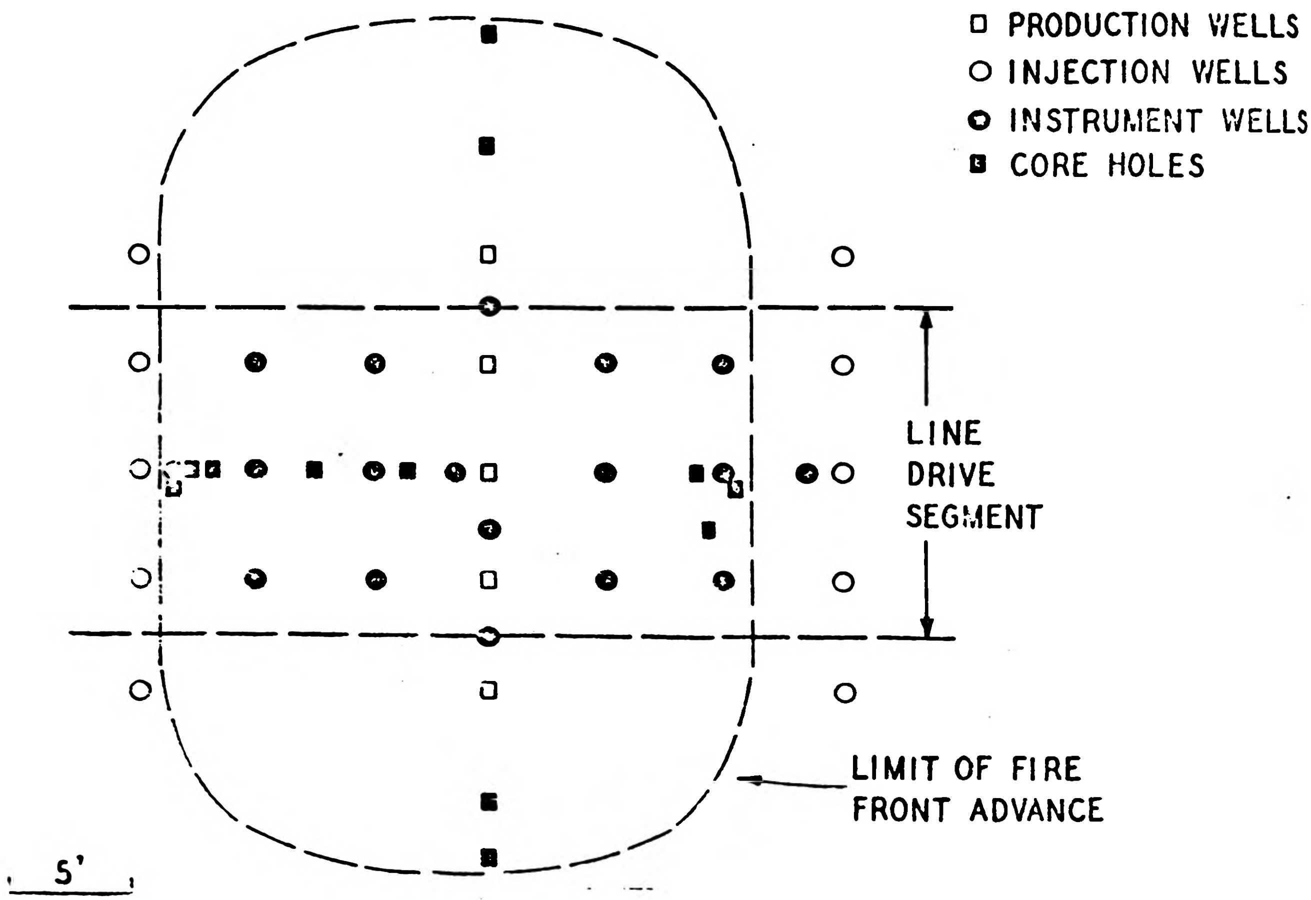

INJECTION WELL
AIR FLOW
PRODUCTION WELL
BURNED OVER REGION
VIRGIN RESERVOIR
FIRE FRONT
TAR BLOCK
(A) DIRECT DRIVE COMBUSTION
INJECTION WELL
AIR FLOW
PRODUCTION WELL
VIRGIN RESERVOIR
(B) COUNTERFLOW COMBUSTION

FIGURE 2



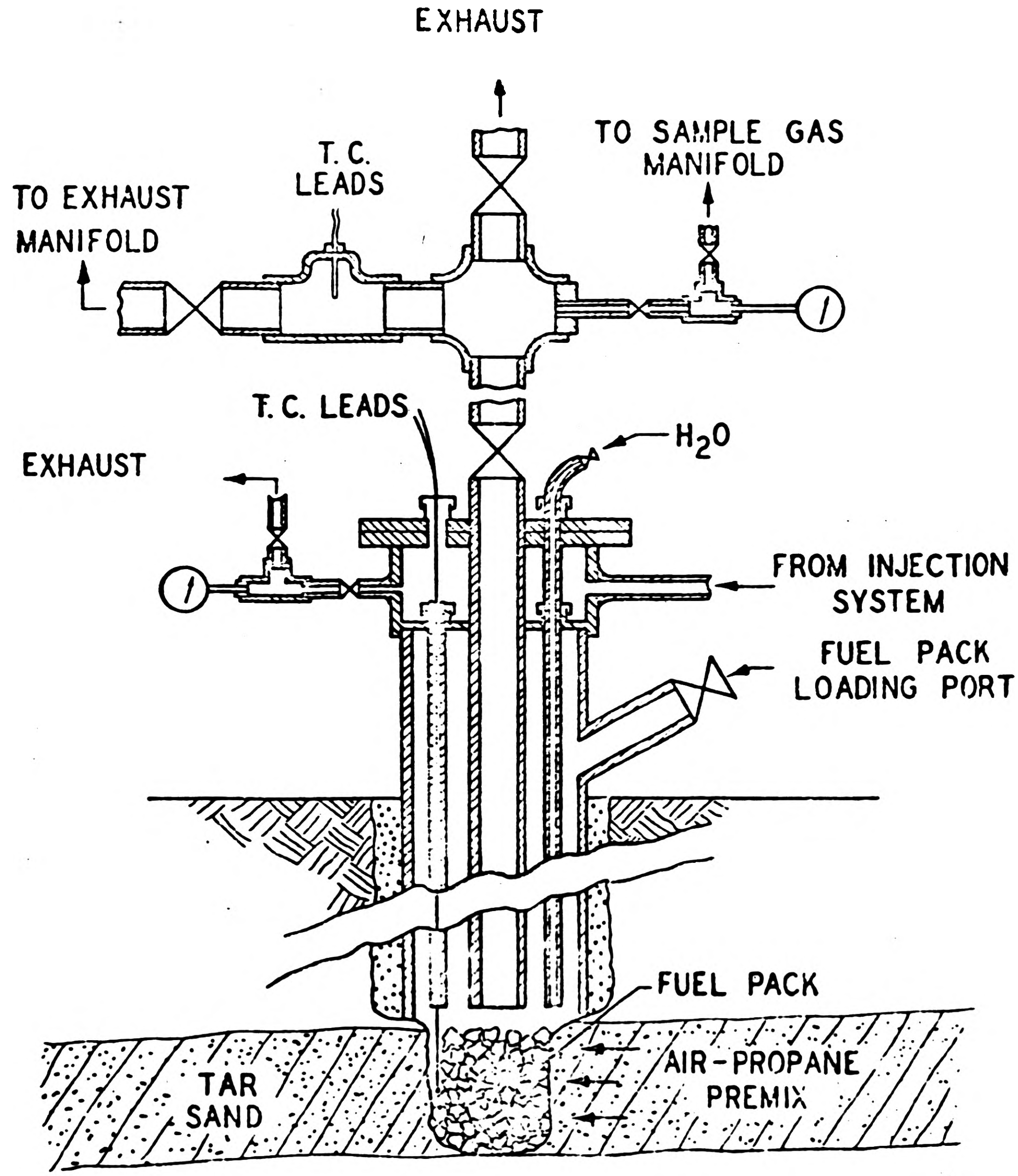
PLAT OF TEST SITE SHOWING TEST PATTERNS

FIGURE 3



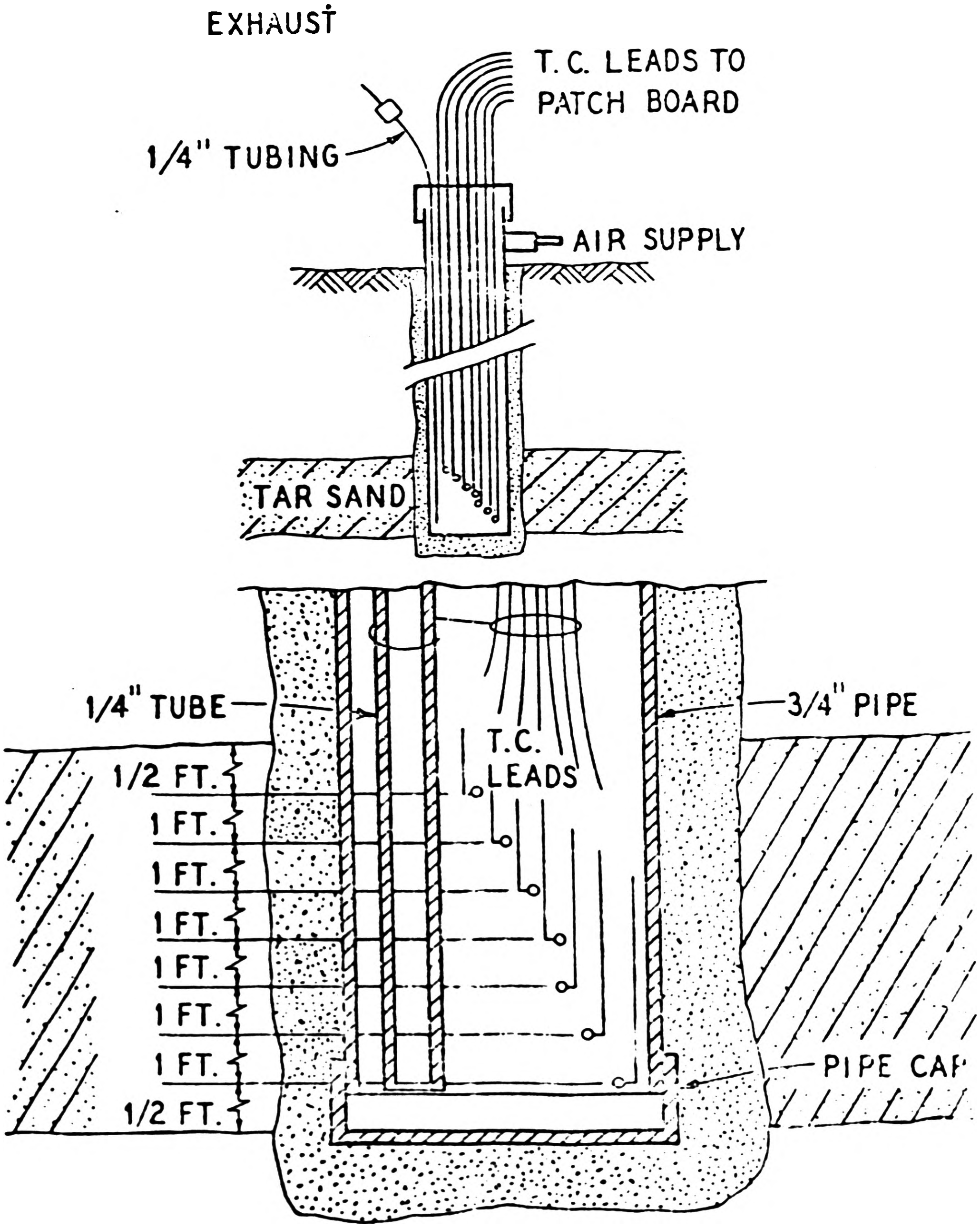
LINE DRIVE PATTERN SHOWING LIMITS OF FIRE FRONT ADVANCE

FIGURE 4



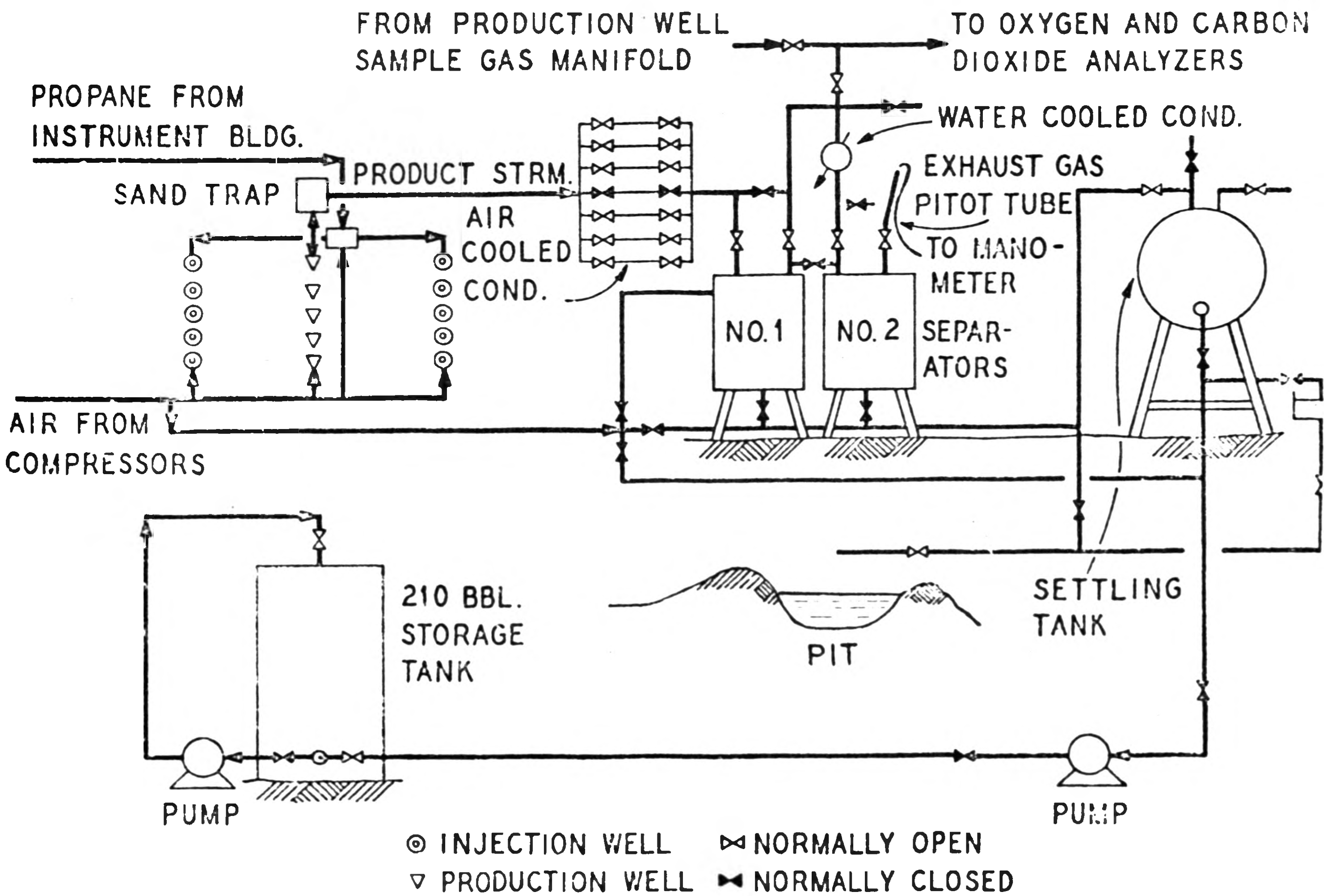
TYPICAL PRODUCTION WELL FOR FUEL PACK IGNITION SHOWING PREMIX INJECTION INTO WELL

FIGURE 5



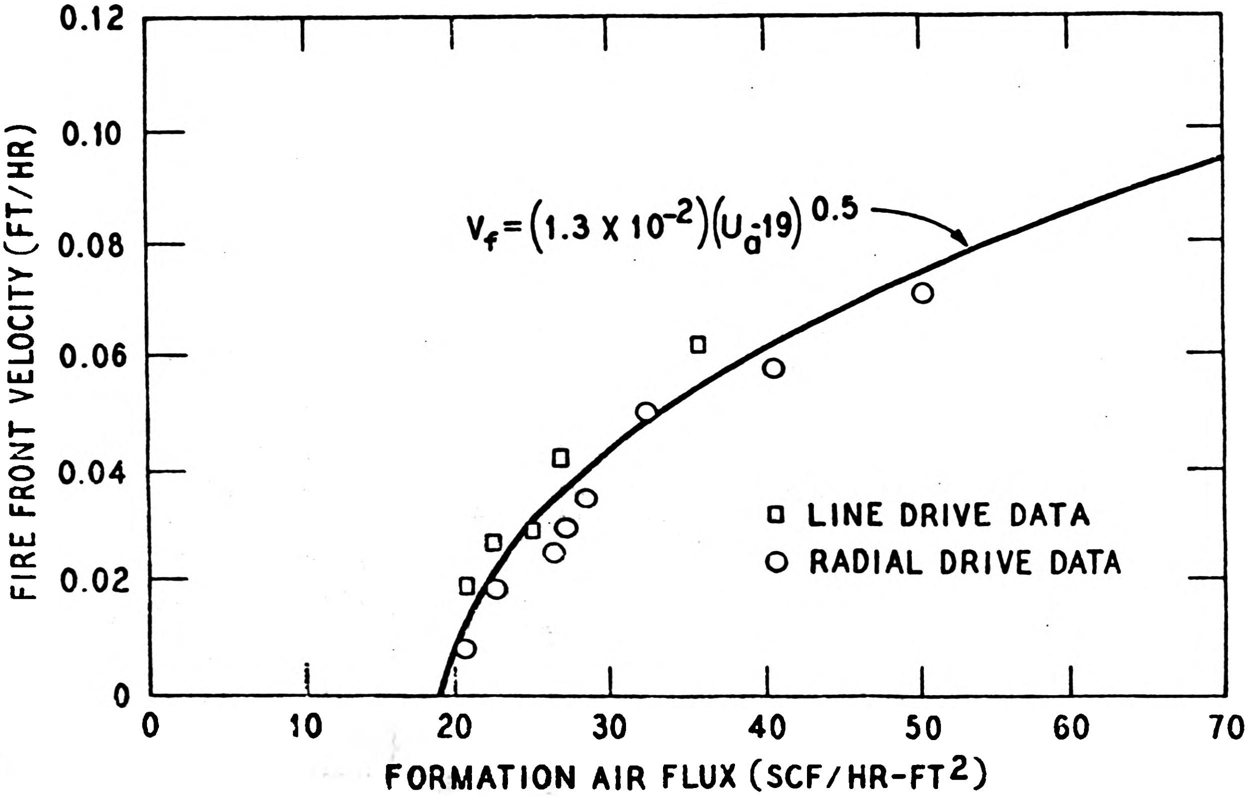
INSTRUMENT WELL

FIGURE 6



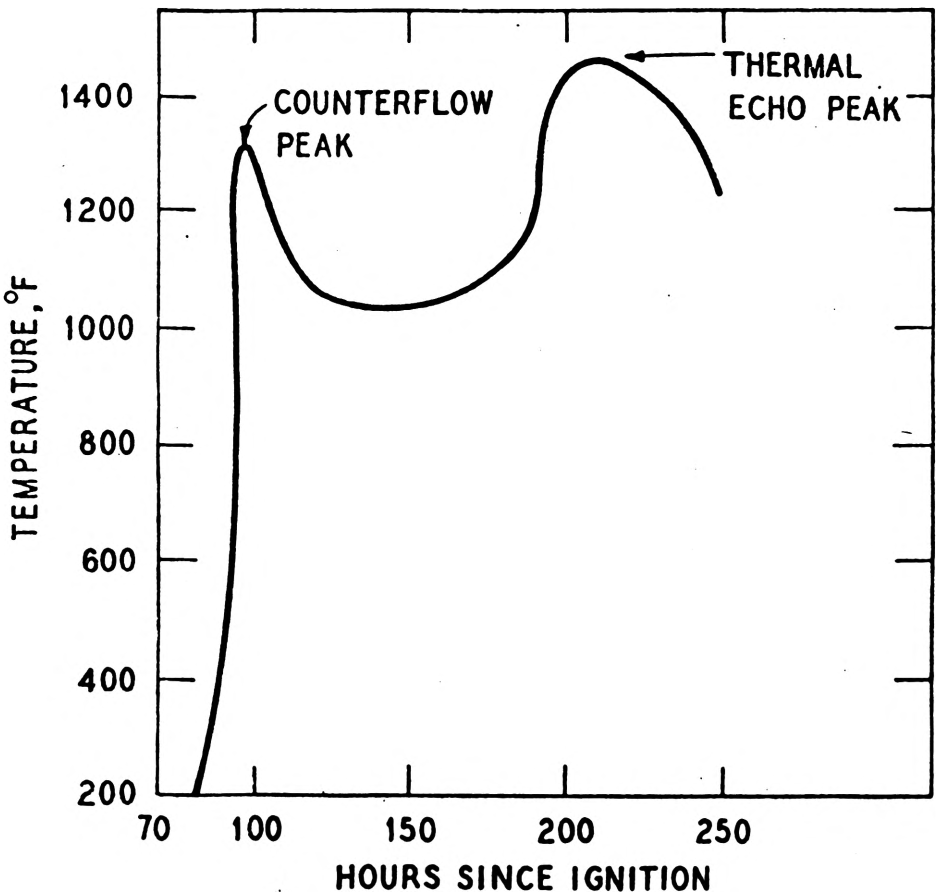
GENERAL FLOW DIAGRAM OF LINE DRIVE EXPERIMENT

FIGURE 7



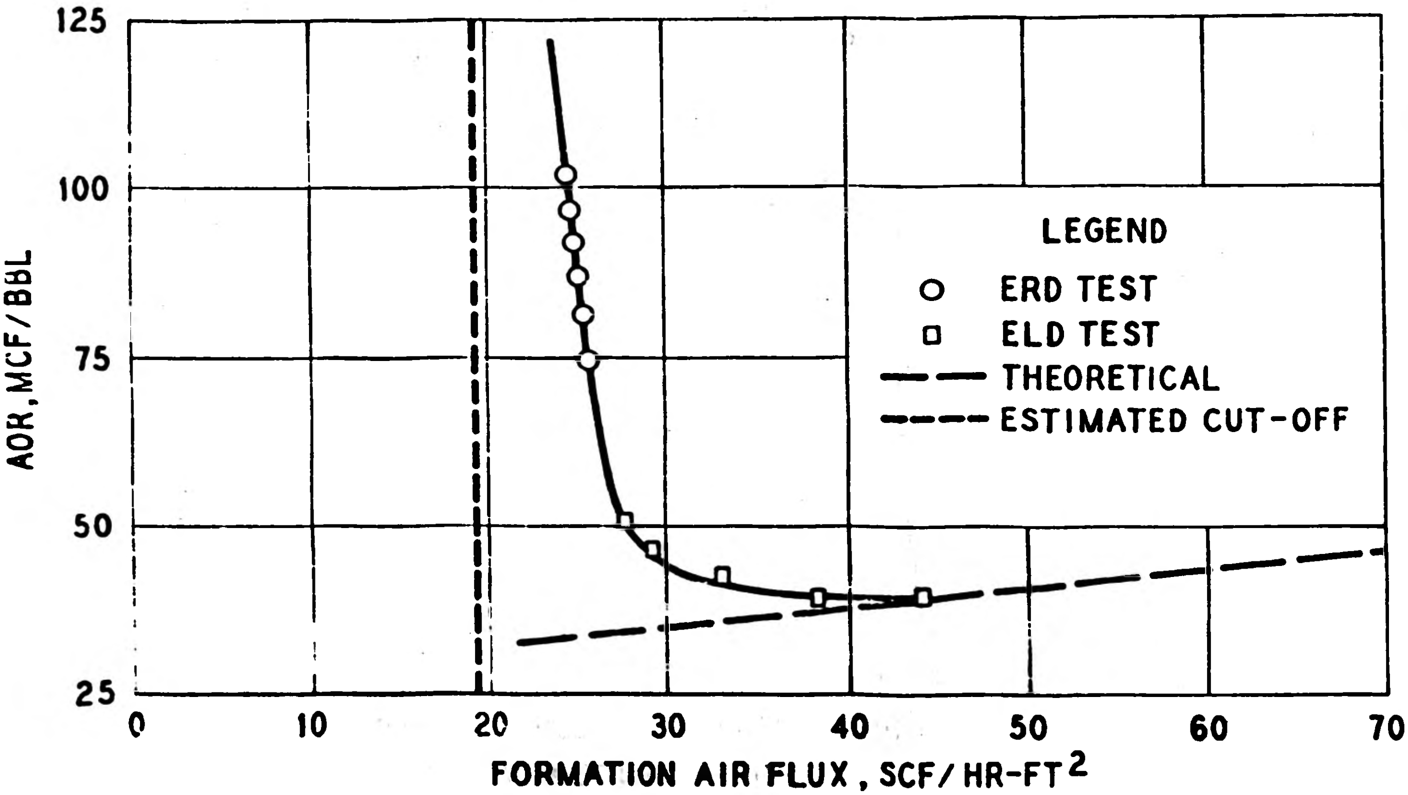
EFFECT OF FORMATION AIR FLUX ON FIRE FRONT PROPAGATION VELOCITY

FIGURE 8



REVERSAL OF BURNING DIRECTION (THERMAL ECHO)
CAUSED BY INSUFFICIENT AIR FLUX

FIGURE 9



AIR-OIL RATIOS (AOR) AS A FUNCTION OF FORMATION AIR FLUX FOR A 1 PERCENT PROPANE-AIR PREMIX

FIGURE 10

OIL SPILL CONTAINMENT AND REMOVAL IN ARCTIC ECOSYSTEMS

Wilfred R. McLeod Diana L. McLeod

Marathon Oil Company
Houston, Texas

ABSTRACT

Statistics on 16 arctic and subarctic oil spills, their locations, the amount of oil spilled, combatant schemes used, and causes for the spills were culled from the literature. This information has been used to analyze the effectiveness of available chemical, mechanical, and destructive means of oil recovery or disposal under arctic and subarctic conditions.

The choice of the best cleanup procedures to follow in any particular instance is clouded by a number of variables and must be weighed against such considerations as wind, sea, and ice conditions, properties of the oil, and effects of chemicals on marine and wildlife. Access to remote arctic sites may well create a major difficulty.

Some recommendations for further research on these problems are also given.

INTRODUCTION

For the purpose of this paper, temperature is the only criterion used to define the limits of the arctic and subarctic regions (Fig. 1). The arctic region is the region in which the mean temperature for the warmest month is below 50°F and the average annual temperature is no higher than 32°F.[1] The subarctic region is the region in which the mean temperature for the coldest month is below 32°F, where the mean temperature of the warmest month is above 50°F, but where there are less than 4 months with a mean temperature above 50°F. The total arctic and subarctic water area is almost 10 million sq miles, compared with approximately 2 million sq miles for the arctic and subarctic land area. The total land and water area is more than 20 percent of the area of the earth.

Oil companies operating in the arctic and subarctic regions are taking greater precautions than ever before to protect the environment. In part this action has been forced upon them by public outcry; but it has also been taken because of technical problems associated with the environment as well as an increased awareness of responsibility to future generations. Their greatest concern is probably associated with the subsequent distribution of the oil.

It is inevitable that oil will get into the arctic and subarctic waters as a result of ship casualties, by accident, or through deliberate discharging of oil into the sea. The main problem facing governments and industry is that of planning effective countermeasures to keep spillage within acceptable limits.

Case histories of 16 arctic and subarctic spills have been analyzed to determine the suitability of current cleanup techniques under these conditions. Fig 1 shows the location of each spill event. The Appendix lists information pertinent to each event.

Behavior of Oil Spilled on Water

Observations made on small-scale tests carried out by the U.S. Coast Guard (USCG) in the arctic failed to discern the changes in spreading regimes as postulated by Blokker and others.[3-7] Comparisons of these theories with field data have not shown good results. This may be due in part to inaccurate field observations or in part to inadequate theories.

Behavior of Oil Spilled on and Under Sea Ice[15, 109]

There are no acceptable theories for predicting the rate of spreading of spilled oil on or under sea ice. However, observations made by various researchers indicate that the rate of spreading of oil spilled on sea ice will vary with the volume and temperature of the oil, with surface conditions, with the configuration of the ice, and with wind speed. A degree of absorption will take place in the surface layers of the ice.

Case studies, along with USCG tests, have indicated the containment possibilities of sea ice. Oil that has found its way under ice will accumulate on the underside of the ice. If the underside contains pressure ridges or pockets, the oil will be bound to the ice by capillary action. Even where the underside of the ice is smooth, the oil adheres more to the ice than to the sea water. This is evidenced by the fact that it is often possible to cut a hole in the ice and, by directing an airstream into the hole, push oil towards a collection point downwind from the sources of the airstream.

CLEANUP METHODS

The containment, collection, and destruction methods currently used to clean up oil spills are shown in Fig. 2. Any or all of these methods may be employed in any given spill event.

Booms and Oil Barriers[12-15]

The popular view is that although the boom concept offers potential for all oil-spill cleanup operations, none of the existing designs have yet proved effective in containing spills in sea states of 3 or greater. This would be particularly true when the containment of oil slicks is attempted in conjunction with or in proximity to ice in its many forms, when such ice will cause an overload on the barrier or boom, ultimately resulting in failure of the containment device.

Slickbar, Inc.,[12] reported that during winter testing of some prototype booms, they accumulated a large quantity of broken skim ice with a section of boom without any adverse effects. The Marsan Corp.[13] carried out attitude tests and evaluated their oil barrier in ice conditions in Lake Michigan in open water with pack ice adjacent where the ambient temperature was below 20°F. Subfreezing conditions did not affect the operation of the boom.

It would be absurd to expect booms or barrier systems to withstand the forces exerted by icebergs, ice floes, or sizable chunks of free-floating ice.

Nevertheless, most oil booms or barrier systems can withstand the cold arctic conditions; that is, they can exceed cold crack tests at temperatures below possible arctic water temperatures. As a result there would be many instances when commercial booms or diverting barriers would be extremely useful if deployed carefully with an understanding of the existing conditions.

Skimmers[16-22]

Mechanical skimmers are being routinely used to remove surface oil from calm water in harbors and waterways. The effectiveness of skimmers in the open sea is yet to be demonstrated.

During the Chedabucto spill, skimmers were used successfully in sheltered water. At the Deception Bay spill, skimmers successfully removed 21 tons of spilled oil. There seems to be a definite place for skimmers in arctic and subarctic cleanup; however, because of the random nature of ice floes and chunks of free-floating ice, skimmer size can become a liability. Therefore, for transportability and maneuverability it probably would be more desirable to use small skimmers in gangs where large capacities are needed.

Dispersants[10, 23, 24]

Ecological considerations, practical experience in this country and abroad, and recent technological developments in the handling of oil spills have pushed the chemical dispersants very much out of the picture. Both the U. S. and Canadian Federal Contingency Plans[66, 67] discourage the use of chemical dispersants, recognizing at the same time that undoubtedly there will be times when dispersants may be the best defensive measure.

In the few instances in which chemical dispersants were used on offshore arctic and subarctic spills, their performance was disappointing. The problem of near-freezing water temperatures, sometimes compounded by the presence of slush or solid ice, caused the viscosity of the oil to increase until dispersants had little effect. Under these conditions, it is extremely difficult to properly apply enough mixing energy to allow the dispersant to work well. In tests carried out in the arctic, the USCG found chemical dispersants inpractical both on water and on ice for the reasons just cited.

Absorbents[25-32]

Generally, tests as well as use in field conditions have shown that the processed materials, such as polyurethane foam, absorb greater volumes of oil per unit weight of sorbent,[15,31,32,109] but natural materials, such as straw, peat, or bark, are more readily available at much lower costs. A common characteristic of all absorbents is that they must be spread on the spill before the oil viscosity increases to the point that absorption is no longer possible. In addition, oil-in-water emulsions, which are difficult to absorb, will eventually form as a result of wave agitation.

As far as the arctic and subarctic offshore areas are concerned, only straw and peat have been tested for their absorbing capacity. Straw has long been a favorite for use in oil-spill cleanup. It is readily available in large quantities, comparatively inexpensive, and absorbs up to five times its weight in oil. Many competent authorities agree that peat has a definite place among oil absorbents. The Irish and Finnish Peat Boards, reporting the results of their own tests, agree that peat possesses the hydrophobic and oleophilic properties that qualify a sorbent for use against oil slicks.[31] Artificially dried peat is more markedly water repellent and appears to be a more satisfactory oil absorbent. It has also been pointed out that while crude oil and distillate oils at normal temperatures are almost instantaneously absorbed by peat, the effect falls off as the oil becomes more viscous. Interestingly enough, during cleanup operations after the wreck of the Arrow in Chedabucto Bay, it was found that the Bunker C oil may not have been absorbed by the peat but that it merely adhered to the surface of the particles in such a way that the whole mass could be removed cleanly. Suitable peat is presently receiving wide use as an absorptive agent in Scandinavian harbors.

The primary difficulty in using absorbents lies in distributing them over the slick, and then harvesting and disposing of the oil-soaked material. Equipment for spreading and harvesting is available for most commercially manufactured absorbents. Natural products such as straw and peat are for the most part laboriously spread and collected by hand. The lack of mechanical means of spreading and collecting these materials has limited their use on large offshore spills. These difficulties have been noted in the arctic tests, and as a result, straw is rated superior to peat on the basis of handling ease along. Although the peat did prove to be more difficult to spread and pick up, the data show that it absorbed more oil both on water and on ice than did the straw.

Some studies have indicated that both peat and straw could be burned in place once the oil has been absorbed. Peat has been successfully burned in place in a number of instances. The Finnish researchers have found it possible to ignite and burn oil mixed with peat even during wintry conditions in water. For best results, the peat must contain less than 30 percent moisture, and a small area of the slick must be covered with peat soaked in kerosene or diesel oil to facilitate the igniting of the oil-soaked peat.

Burning[32-39]

Experimental as well as actual oil burns in the arctic and subarctic with and without fire promoters and burning agents involving oil on cold water and oil on ice have demonstrated the effectiveness of this method. In reporting the results of their arctic burns, the USCG made the following observations: (1) The ability of North Slope crude oil to burn seems to be virtually unhampered by its residence on ice. (2) The burning agent has some effect on the residue. (3) Ice and snow aid combustion by providing a wicking action. (4) The wind is a definite factor in forcing the oil into pools thick enough to support combustion without the presence of burning agents. It was also observed that above a certain wind velocity, blowing snow extinguishes the fire. Snow either blowing or falling onto oil will form a "slush" containing up to 80 percent snow.[109] Since these slushes will not ignite, they present a considerable cleanup problem. At the present time, the only means of disposal seems to be to collect the slush, melt the snow, and then separate the resulting oil-water mixture. This becomes a laborious and difficult procedure if one is dealing with a large spill in an isolated arctic location.

The U. S. and Canadian governments agree that burning agents and techniques may be used and are acceptable, so long as they do not in themselves, or in combination with the material to which they are applied, increase the pollution hazard.

Biodegradation[40-50]

There are hundreds of articles in the literature pertaining to hydrocarbon microbiology. Refs. 40 through 45 are among those most often quoted.

Kriss[40,41] points out that although the arctic and subarctic waters are areas of very low microbial population density, these regions are highly likely to contain more strains of microorganisms that hydrolyze proteic substances and ferment carbohydrates--petroleum-metabolizing bacteria--than are the tropical regions. He also observed that there are seasonal fluctuations in the development of microbial life in the central part of the arctic ocean under the pack ice. The period of depressed activity corresponds to the advent of the dark period of the year and occurs in spite of the practically unchanging temperature of the water.

The rate of decomposition of oil by microbial action depends on the number and type of organisms present, the amount of oxygen available, the physical state and chemical nature of the oil, as well as many environmental factors; it is by no means easy to predict. In general, the process seems to be more rapid if the oil is in the form of an oil-in-water emulsion, oil adsorbed on solids, and thin flims of oil floating on the sea than if it is in a large coherent mass. It is widely recognized that sinking agents and dispersants may also affect the rate of bacterial degradation. However, studies to determine these effects have thus far been inconclusive. Even the highest estimated rate of biological decay (350 gm/cu in/yr) would be much too slow to rely on as a way of cleaning up major oil spills.

Recently there has been much speculation on the seeding of oil slicks with microorganisms to hasten the natural degradation process. Whether or not this approach is practical is still open to question.[47]

CONTINGENCY PLANS[66-70]

The federal governments of both Canada and the U. S. have drawn up contingency plans for oil spills that not only serve as a guide for action on the national level in case of massive spills, but also provide an outline for the development of regional and local planning in the event of small spills.[66,67] Both plans show a number of similarities. Each country and its offshore areas is divided into several regions and subregions. On-scene coordinators (OSC) are provided for and their duties are defined. Alerting and reporting procedures in the event of an oil spill are designated. Recommended techniques and equipment for handling oil spills are described. But the actual procedures to be followed for any given spill are left to the discretion of the OSC, who must consider such factors as location and size of spill, weather conditions, and the environmental effects of the spilled oil and of the cleanup techniques.

Private companies and oil company cooperatives have also formulated their own contingency plans in accordance with federal regulations. By the end of 1972 there were 84 cooperatives in operation in the U. S., and at least 17 others were being developed. Their contingency plans are expected to enable the petroleum industry to handle minor or moderate spills without direct assistance from federal sources.

To our knowledge, there is currently only one U. S. cooperative in operation in the arctic and subarctic regions - the Cook Inlet Cooperative, formed in May 1970.

CONCLUDING REMARKS

In the Arctic, whether on land or water, most of the currently available cleanup methods will find applications although human discomfort coupled at times with visibility-limiting conditions will hamper control and recovery efforts. This, in turn, will cause the unit cost of cleanup to vary considerably.

In the 16 arctic and subarctic spills studied, commercial booms have, for the most part, been disappointing because the oceanographic and environmental conditions encountered were more or less outside the accepted range of applicability of current designs.

In field tests carried out by commerical boom manufacturers, sub-freezing temperatures do not affect the performance of their booms. Therefore, it is more likely that oil barrier boom systems will find use in arctic and subarctic waters provided open water could be assured. Unconventional booms made of such materials as logs or wire and spruce boughs are also a likelihood.

The case studies along with the USCG tests have indicated the containment possibilities of sea ice. Oil which has found its way under ice will accumulate on the underside of the ice. If the underside contains pressure ridges or pockets, the oil will be bound to the ice by capillary action. Even where the underside of the ice is smooth, there is greater coupling between the oil to the ice than to the sea water. This is evidenced by the fact that it is often possible to cut a hole in the ice and by directing an airstream into the hole push oil towards a collection point downwind from the sources of the airstream.

Ice floe or iceberg "booms" are another possibility since some oil companies active in the Arctic have shown that the idea of "roping" an iceberg and towing it into a pre-designated position is feasible.

The use of chemical dispersants has not been ruled out by either the U. S. or Canadian environmental agencies. Generally speaking, it is unlikely that existing water-base dispersants would be useful in the Arctic since most of them would freeze in the extreme cold. It is possible that a new generation of non-water-base dispersants may find use.

Physical removal of an oil slick is the most positive way of dealing with oil pollution. Absorbents offer such a means. Laboratory tests have shown that commercially prepared absorbents such as polymeric foams, polyethylene and polypropylene fibers have the highest sorption capacities for oils. However, these materials have not been used extensively in oil spill clean-up because of their relatively high cost in comparison to such naturally occurring absorbents as peat and straw. In arctic and subarctic regions where availability of the natural absorbents and distance of the spill from logistic supply sources are significant factors, the higher absorptive capacities and the secondary recovery features of synthetic materials may offset the initial cost advantages of the naturally occurring absorbents. Another advantage of the synthetic materials may be that they produce cleaner residues when the oil-soaked absorbent is burned.

In those spill events where clean-up procedures are described, burning is the ultimate method of oil disposal. Field tests demonstrated that North Slope crude and Arctic diesel oil will ignite and burn on ice, snow or in cold water either with or without fire promoters. It is suspected that the disposal of

Bunker C or other heavy oils by burning would require the use of burning agents. However, the added task associated with the removal of the increased residue resulting from the use of fire promoters is of concern.

The primary areas for further research seem to be in the development and manufacture of cheaper synthetic absorbents with high oil absorption capacities, means of mechanically spreading and collecting the absorbent, harvesting oil from the absorbent, and re-use or disposal of absorbents. In addition, investigations should be carried out on collection and disposal of residues from burning and treatment or disposal of snow-oil slushes.

During test spills, absorbents were spread and collected manually. In the event of a large spill, however, more effective and faster methods requiring fewer man-hours would undoubtedly be necessary. Moreover, some means for mechanically mixing the absorbent with the oil may be required to insure optimum performance. Recovery of the absorbed oil and subsequent re-use of the absorbent offer a potential economic benefit in the reduction of cleanup costs.

If weather and slick characteristics permit, burning can dispose of 70 to 90% (by volume) of the spilled oil. Disposal of the burned residue from large spills could present a pollution problem approaching in magnitude that of initial treatment of the spill. Schemes for removal and ultimate disposal of this residue need to be developed.

Snow either blowing or falling onto oil will form a "slush" containing up to 80% snow.[109] Since these slushes will not ignite, they present a considerable cleanup problem. At the present time, the only means of disposal seems to be collecting the slush, melting the snow, and then separating the resulting oil-water mixture. This becomes a laborious and difficult procedure if one is dealing with a large spill in an isolated Arctic location. An effective scheme for dealing with these slushes will also be needed.

The original manuscript (SPE 3931, OTC 1523) was presented at the Fourth Annual Offshore Technology Conference, held in Houston, Texas, May 1-3, 1972. A revised version was printed in the March 1974 issue of the Journal of Petroleum Technology.

APPENDIX

Case Histories: Arctic and Subarctic Spills

Date of Spill: Spring 1958.
Location: Mackenzie River (Norman Wells) Canada
Cause and Extent of Spill: A break or draining of a pipeline across the river ice spilled an undetermined amount of crude oil on the ice.
Environmental Conditions: River iced over.
Cleanup Procedures: Oil confined by log booms and burned.

Date of Spill: Winter 1968-69.
Location: Tuktoyaktuk Harbor, 26 km east of the Mackenzie River Delta.
Cause and Extent of Spill: A leak or break in a large fuel tank owned by Northern Transportation Co. Ltd. spilled thousands of gallons of diesel fuel onto the ice.
Environmental Conditions: Harbor was iced over.
Cleanup Procedures: Local residents scooped up most of the fuel, separated it from ice and snow in barrels, and used it to augment their supply of household fuel.

Date of Spill: March 3, 1969.
Location: Cook Inlet, Alaska.
Cause and Extent of Spill: The tanker Yukon was damaged when it struck a submerged object and spilled a small amount of oil into Cook Inlet. The Coast Guard reported an oil slick 10 miles wide and 18 miles long.
Environmental Conditions: None given.
Cleanup Procedures: Chemical dispersant was flown to the site but not used. Surveys a few days after the incident revealed no trace of oil. It was assumed the oil was dispersed by ice and heavy tides.

Date of Spill: June 23, 1969.
Location: Cook Inlet, Alaska (II).
Cause and Extent of Spill: Because of machinery and a considerable internal spill of fuel oil, a Liberian tanker left a wake of contaminated water the full length of Cook Inlet.
Environmental Conditions: None given.
Cleanup Procedures: None.

Date of Spill: Dec. 2, 1969.
Location: Channel between the islands of Emasalo and Kalvo, Finland.
Cause and Extent of Spill: Oil thought to be discharged from the engine room of the 43,000 DWT Greek oil tanker Neil Armstrong caused an oil film approximately 3 to 4 km x 200 m.
Environmental Conditions: None given.
Cleanup Procedures: None given.

Date of Spill: Dec. 9, 1969.
Location: Ajax Shallows, 17 km southeast of Hanko at the entrance to the Gulf of Finland.
Cause and Extent of Spill: 5,860 DWT Finnish cargo ship Eira went aground and sank, releasing approximately 15,000 liters of diesel oil. A slick approximately 18 km x 20 to 30 m was observed.
Environmental Conditions: Snowing.
Cleanup Procedures: Booms - used unsuccessfully. Burning - oil was burned using paraffin oil as a fire promoter.

Date of Spill: Dec. 15, 1969.
Location: West of Emasalo, Finland.
Cause and Extent of Spill: 50,000 DWT Russian tanker, the Raphael, went aground, spilling more than 60 tons of crude oil, which formed a slick 10 km long and several meters wide.
Environmental Conditions: Snowing.
Cleanup Procedures: Booms - used unsuccessfully. Burning - peat, fuel oil, and petrol used as fire promotors and burning agents to remove 90 percent of spilled oil.

Date of Spill: Feb. 4, 1970.
Location: Chedabucto Bay, Nova Scotia.
Cause and Extent of Spill: The Liberian-registered tanker, Arrow, carrying 16,000 tons of Venezuelan Bunker C fuel oil went aground and broke up, spilling most of the oil into the bay. Several slicks formed and 190 miles of coastline were polluted.
Environmental Conditions: Water temperature 0°to 1°C; air temperature much lower. Storm winds 40 to 50 mph. Severe wave conditions. Water depth, about 100 ft.
Cleanup Procedures: Booms - floating booms were unsuccessful. Homemade booms of wire mesh covered with spruce boughs were more successful than commerical semiflexible, nonporous booms. Skimmers - "slick-lickers" were used successfully in sheltered waters. Dispersants - Corexit 8666 was sprayed on the slick, but could not penetrate thick layers of oil that

formed as a result of low temperatures and weathering; BP1100B was effective in removing oil on rocks. Absorbents - peat moss proved to be a good absorbent; straw was used on some beaches. Burning - wicking agent, SeaBeads, used successfully on beaches and on isolated slicks in 1^{o} to $2^{o}C$ water; part of spill was burned by spilling two drums of fresh oil and igniting it with Kontax; onshore oil deposits at Arichat were ignited with mapalm and a flame thrower and burned well.

Date of Spill: Feb. 1970.
Location: Kodiak Island, Alaska.
Cause and Extent of Spill: Ballast discharges from tankers enroute to Cook Inlet washed ashore, polluting 1,000 miles of shoreline.
Environmental Conditions: None given.
Cleanup Procedures: None.

Date of Spill: March 20, 1970.
Location: Tralhavet Bay, Sweden.
Cause and Extent of Spill: The tanker Othello collided with another tanker, the Katelysia, spilling 60,000 to 100,000 tons of Bunker C fuel oil The oil formed large blobs 0.45 to 0.6 in. in diameter, which sank except for a few centimeters showing at the surface.
Environmental Conditions: Low temperature; harbor ice was in the process of breaking up.
Cleanup Procedures: Because of the coldness of the waters and the formation of icepacks, the dispersants, absorbents, and containment booms were impractical. Wicking agent Cab-O-Sil ST-2-O was used successfully to burn oil.

Date of Spill: April 1970.
Location: Unimak Island, Alaska.
Cause and Extent of Spill: Spill of highly toxic diesel oil of unknown source polluted shores of Unimak Island.
Environmental Conditions: None given.
Cleanup Procedures: None.

Date of Spill: April 25, 1970.
Location: Alaska Peninsula, Egegik to Port Moller.
Cause and Extent of Spill: Diesel fuel from two Japanese ships that sank in a storm April 21-22, 1970, formed a slick 10 miles wide, which washed ashore, polluting 700 miles of coastline.
Environmental Conditions: None given.
Cleanup Procedures: None.

Date of Spill: June 6, 1970.
Location: Deception Bay, Quebec (Western Judson Strait).
Cause and Extent of Spill: A slush avalanche moving through a tank farm damaged five storage tanks, which spilled 369,000 gal of arctic diesel fuel and 58,000 gal of gasoline. The affected areas were the permafrost just below the tank farm, the shorefast ice, the tidal crack network, and the sea ice.
Environmental Conditions: A flat expanse of sea ice covered all of the bay and closely spaced blocks of ice over most of the intertidal zone. Daytime temperatures ranged from 34^{o} to $40^{o}F$. Winds varied from calm to 35 mph.
Cleanup Procedure: Skimmers - a skimmer of 7 kg/sec capacity was used to reclaim 21 tons of oil trapped in pools. Burning - oil on the ice and contained by near-shore ice was burned; the remaining oil was pumped onto the ice from the water and burned. All of the oil was cleaned up by repeated burns.

Date of Spill: June 6, 1970.
Location: Athabasca River, Alberta, Canada.
Cause and Extent of Spill: 17,000 bbl of oil spilled onto the river bank from a break in a 16-in. pipeline. Oil in the river was carried rapidly downstream to the Athabasca Lake.
Environmental Conditions: 45-mph winds.
Cleanup Procedures: Booms - booms were set up to prevent the flow of oil into the Slave River system. Skimmers - a "slick-licker" was brought in but not used for lack of a suitable mounting craft and because of high winds. Winds dispersed the spill within 2 days.

Date of Spill: July 1970.
Location: Oslofjord, Norway.
Cause and Extent of Spill: Deteriorating fuel tanks of a German cruiser that had sunk on April 9, 1940, in about 33 ft of water released oil into Oslofjord. The tanks contained about 1,800 metric tons of oil.
Environmental Conditions: None given.
Cleanup Procedures: None given.

Date of Spill: Sept. 7, 1970.
Location: 47°22'N, 63°20'W in the Gulf of St. Lawrence near Prince Edward Island.
Cause and Extent of Spill: The oil barge Irving Whale sank in 75 m of water. It carried approximately 4,000 tons of Bunker C fuel oil (pour point $12^{o}C$). Within 3 days, leaking oil formed lenses occupying an area 30 km long and 15 km wide.
Environmental Conditions: Water temperature was $12^{o}C$ at the surface and $0^{o}C$ at 75 m under the surface. Four days after the sinking, a storm caused winds of 10 m/sec.
Cleanup Procedures: Booms - booms were used to protect harbors and shore; a boom around the barge sank after 4 days of high winds and heavy seas. Absorbents - peat moss was spread on the bands of oil. Dispersants - limited amounts of dispersants were used. High winds and waves caused by the storm broke up the oil slick. Weathered oil lumps, which later washed up on beaches, were easily removed with forks and shovels.

U. S. Coast Guard Oil-Spill Test Program

Date of Spill: Summer 1970.
Location: Point Barrow, Alaska.
Cause and Extent of Spill: The U. S. Coast Guard conducted tests to study the behavior of oil in the arctic and possible cleanup procedures. Approximately 55 gal of North Slope crude oil was used in each of several tests.
Environmental Conditions: Ice temperature - $0.3^{o}C$. Water temperature - 1^{o} to $2^{o}C$. Air temperature - 1^{o} to $4.8^{o}C$.
Cleanup Procedures: Burning - fresh and 6-day-old crude oils ignited and burned well both on water and on ice; no difference in ignition and burning was noted when either a glass bead or fumed silica burning agent was used. Absorbents - peat moss and straw were effective absorbents, with peat moss showing greater absorption both in water and on ice; however, straw was much easier to handle. Dispersants - chemical dispersants tested were judged impractical because conditions made it difficult to supply adequate mixing energy.

Date of Spill: Jan. and Feb. 1972.
Location: Port Clarence Bay, Alaska.
Cause and Extent of Spill: Further U. S. Coast Guard tests. Approximately 55 gal of North Slope crude oil was used in each of the tests.
Cleanup Procedures: Burning - 24-hour-old crude oils burned well on both snow and ice without the use of burning agents; approximately 70 percent of the oil

on snow and 90 percent of that on ice was destroyed by burning; fires were extinguished when winds increased above 14 knots.

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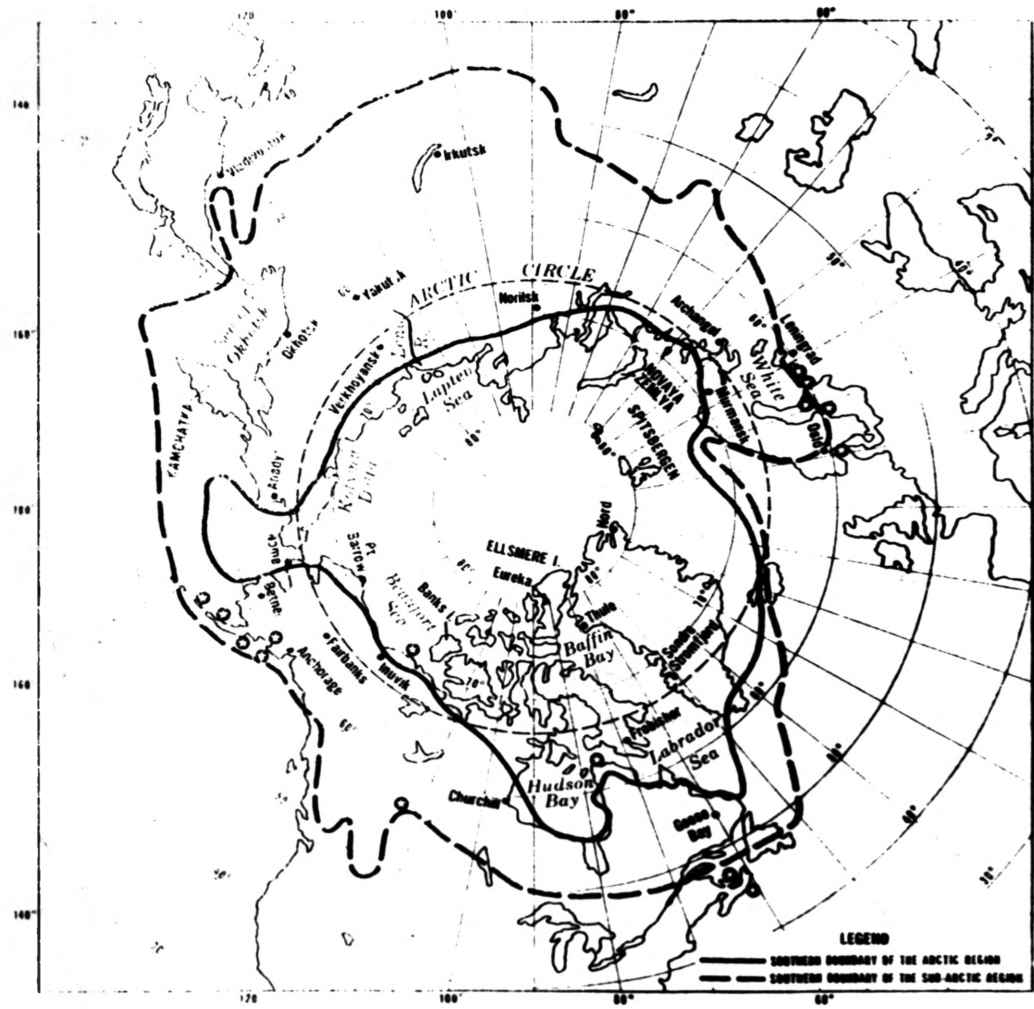
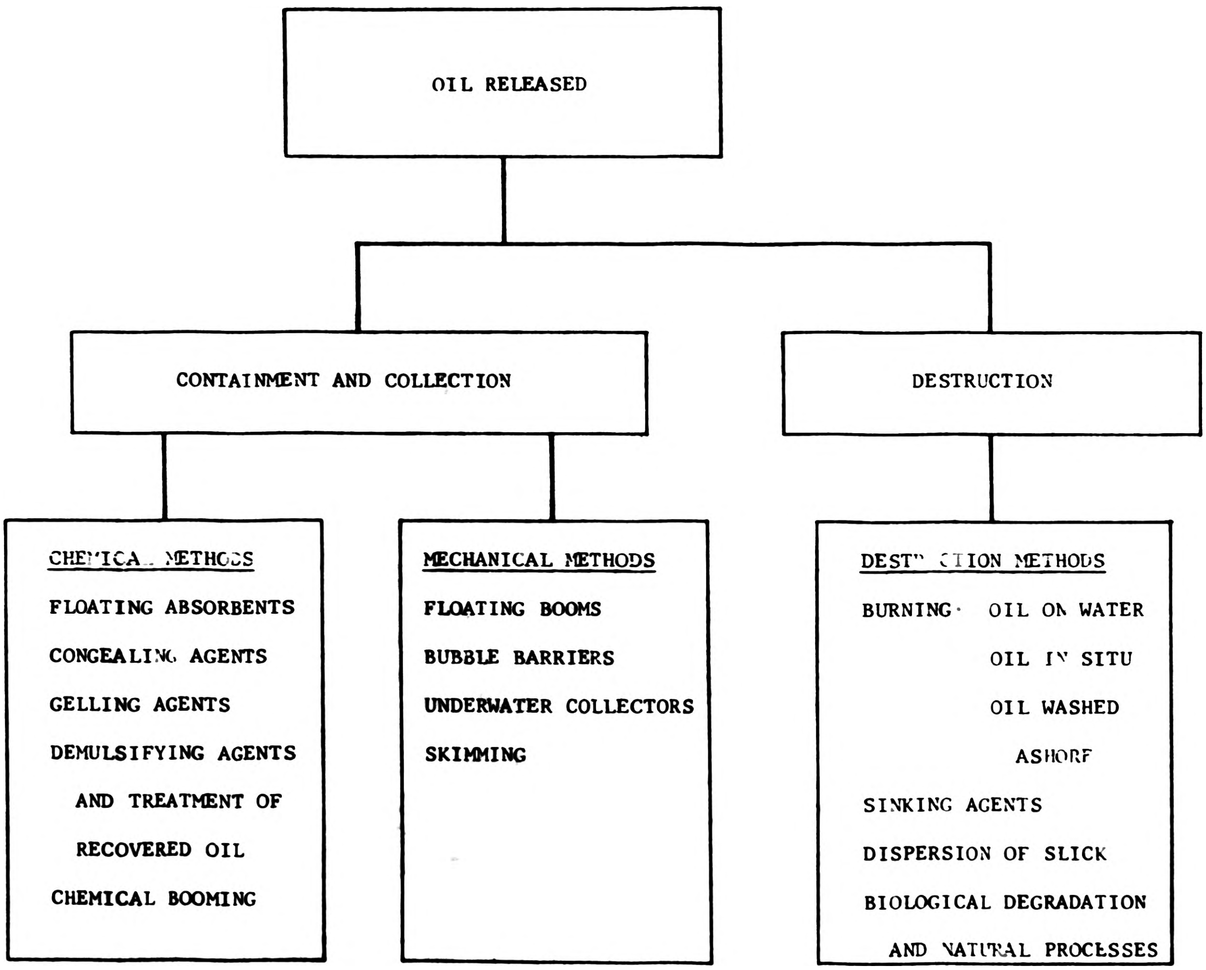


Figure I NORTH COLD REGIONS: POLAR LIMITS AND ZONES.

FIGURE II - CONTAINMENT, COLLECTION AND DESTRUCTION METHODS



MISSOURI COAL IN PERSPECTIVE

Charles E. Robertson
Missouri Geological Survey & Water Resources
Rolla, Missouri

ABSTRACT

Missouri's coal resource base of 49 billion tons is part of the 132 billion ton coal resource base of the Western Interior Coal Region of Missouri, Iowa, Kansas, Arkansas and Oklahoma. The energy content of this coal resource base is 2,600 quadrillion Btu, more than the amount of energy contained in all the petroleum produced to date in the United States.

This large energy resource cannot remain ignored in a time of energy crisis such as the present. It is recommended that research efforts be stepped up that will permit recovery of energy from the thin, high sulfur seams of the Western Interior Region.

It is recommended that research focus on (1) developing desulfurization and coal conversion technology to allow the use of high sulfur coal in compliance with environmental standards (2) lowering production costs (3) developing technology which will allow the mining of thin seams and deep coal and (4) improving reclamation methods. Conversion of coal to low-Btu gas or solvent-refined coal and in-situ gasification of coal are considered to be especially important research areas.

Research facilities should be located in the Western Region to facilitate application of the results to mining conditions and coal characteristics prevailing in the region.

Missouri, with the greater share of the Region's coal, is a likely candidate for research facilities to be established in the region.

INTRODUCTION

The current energy crisis has brought into focus the potential importance of coal in providing needed energy to meet the nation's growing demands. For although oil and gas now supply 78 percent of the nation's energy requirements and coal only 17 percent, reserves of coal represent 80 percent of the nation's conventional energy reserve and 85 percent of the nation's fossil fuel reserve.

Despite energy conservation programs the demand for energy continues to increase. The demand for fossil fuels is expected to double by the year 2000 (only 26 years hence). Should nuclear power fail to materialize as expected the demand for fossil fuels will be even greater.

Domestic supplies of crude oil and natural gas cannot keep pace with future demand, and increasingly heavy reliance on foreign imports is unthinkable for obvious reasons. Only coal is available in large enough quantities with existing technology to meet the nation's energy needs in the next several decades.

Under the President's energy self-sufficiency program coal will be called upon not only to perform its present function as a fuel for electric power generation, but also to fill the energy gap being created by dwindling supplies of oil and gas. If coal is to fill this gap, great amounts of coal will be mined in the decades ahead and deposits now thought uneconomical to mine will become economical. Production will be needed from every known coal field.

The Western Interior Coal Region of Missouri, Iowa, Kansas, Arkansas and Oklahoma contains a coal resource base of 132 billion tons. The energy content of this coal resource base is 2,600 quadrillion Btu, more than the amount of energy contained in all the petroleum produced to date in the United States. This large energy resource cannot be ignored in a time of energy crisis such as the present. It is the purpose of this paper to recommend that research and development programs that will facilitate development of this significant energy resource be pursued.

Missouri's coal resource base is greater than that of any other state in the Western Interior Region. In fact, Missouri ranks 10th nationally among the 27 states containing reserves of bituminous coal. Over 6 billion tons of Missouri's 49 billion tons resource base is technically recoverable. This represents more than 132 quadrillion Btu of technically recoverable energy. Much of the remaining 43 billion tons which is now considered unrecoverable could be converted to a recoverable reserve by a combination of technological research and continued exploration.

Therefore, Missouri, with the greater share of the Region's coal, is a likely candidate for research facilities which should be established in the Western Interior Region to facilitate application of the results to mining conditions and physical and chemical characteristics of the Region's coal.

The coal beds of the Western Interior Region are beset by common problems. The two most serious problems are (1) a tendency of the beds to be thin and (2) high sulfur content. The thin nature of the beds makes underground mining difficult and costly and the high sulfur content precludes the use of these coals for direct combustion without costly (and thus far ineffective) desulfurization. The fact that much coal in the Western Interior Region is strippable has in the past allowed it to be mined competitively. Strip mining continues to be the primary mining method, and this creates environmental problems which require solution.

Future expansion of coal production in Missouri and other states of the Western Interior Region will be contingent upon several factors. Production costs must be kept at a minimum to allow economic competition with other coal producing regions. Economic methods of producing low-sulfur fuels from the Region's high-sulfur coals must be developed. Improved methods of mined land reclamation must be developed to allow strip mining with minimum environmental damage and lower reclamation costs. Research must be oriented toward solution of these problems.

The states of the Western Region have not been neglectful of their coal resources. The Iowa Geological Survey is conducting a drilling program with the evaluation of reserve tonnage, coal quality and stratigraphic relationships as objectives. Iowa also is planning an experimental strip mine to study mining, coal beneficiation and reclamation methods. The Kansas Geological Survey is presently re-evaluating that state's reserves and evaluating alternate coal-mining methods for thin seam coal. The Kansas Survey has also been active in mined-land reclamation research.

In Oklahoma, a recent feasibility study has demonstrated that it is economically workable to construct a coal gasification plant in eastern Oklahoma. For the past several years the Missouri Geological Survey has been mapping and re-evaluating Missouri's coal resources. Core-drilling and coal sampling, with accompanying analysis, were conducted as part of this program. The Missouri Survey is currently developing plans for a study of the alternate roles that the future development of coal in Missouri might take. The Survey's objective will be to attempt the identification of the most probable modes of utilization of these coal resources, their short and long-term benefits with respect to the state's economy, as well as the costs that various modes of development might impose on our environment and upon our other natural resources.

Future research on Missouri coal should focus on four areas: (1) Developing methods which will allow the use of high sulfur coal in compliance with environmental standards (2) lowering production costs (3) developing technology which will allow the development of thin seams and deep coal and (4) improving reclamation methods.

For high sulfur coal to be made usable under prevailing emission standards, technology must be developed and refined to (1) desulfurize the coal during combustion or the stack gasses after combustion and (2) convert the coal to clean-burning gas or oil. Pilot or demonstration facilities should be erected to facilitate development of these processes.

Direct combustion of coal, without an intervening conversion phase, has the advantage of better energy efficiency. Conversion of a fuel from one form to another (coal to gas or oil) is always accompanied by an energy loss (usually 20 to 30 percent). Therefore, successful use of desulfurization methods would have the effect of conserving energy. In order to be effective in this way, however, the desulfurization process must not be a flagrant consumer of energy. For instance, the quarrying, grinding and transportation of limestone or dolomite for desulfurization consumes an amount of energy that must be taken into account. The development, then, of an energy efficient, economically feasible, effective method of desulfurization should be a primary research goal in regard to utilization of Missouri coal.

Conversion of coal to clean-burning fuels offers another solution to the sulfur problem inherent in Missouri coals. There are many conversion processes under development, but all of them may be grouped under the following categories: (1) gasification, (2) liquefaction, and (3) solvent refining. Missouri coals are high volatile bituminous in rank and most of them are of the caking variety. These factors must be taken into account when designing conversion processes for Missouri coal. Technically, Missouri coals can be converted to liquid, gaseous or sulfur-free solid fuels. Some of the more promising applications are discussed below.

Missouri coals can be converted to either high or low-Btu gas. The caking characteristic of Missouri coals make it necessary to pretreat them for some gasification processes. Production of low-Btu gas for industrial and utilities use may prove particularly applicable to Missouri. Low-Btu gas for industrial use is not a new idea. Early in the present century low-Btu (producer) gas was used for boiler heating, ore roasting and lime and cement manufacturing. Production of gas at large central mine-mouth plants with distribution through pipe systems was proposed. The availability of cheap natural gas soon aborted this concept, but now with natural gas in short supply perhaps the use of low-Btu gas will once again become widespread. Low-Btu gas might prove applicable to the state's industrial needs which are now largely dependent upon natural gas.

A very intriguing concept for the production of gas from Missouri coal is in-situ gasification. Its benefits are obvious. If it proves economically feasible, this method will allow production of a clean gas from coal by burning the coal underground and recovering the gas thus produced through gas wells, thus greatly reducing environmental degradation. In-situ gasification also offers the prospect of recovering coal from seams that are too thin or too deep to mine and therefore would have the effect of actually increasing the state's reserve of recoverable coal. The gas produced by the in-situ process could either be used at or near the production site as a low-Btu gas for electricity generation or for industrial process or it could be upgraded by methanation to a pipeline quality gas.

Missouri coal can be converted to synthetic petroleum by hydrogenation. It can also be converted to a clean-burning, low-sulfur solid fuel by solvent refining.

A critical factor relating to the development of a successful coal conversion industry in Missouri is the problem of acquiring blocks of coal which are large enough and which can be mined cheaply enough to meet the economic requirements of coal conversion. There will be strong competition, especially in the next decade from states possessing greater reserves of thicker and therefore more cheaply mined coal.

Offsetting this negative factor is the comination of adequate supplies of water in close proximity to adequate uncommitted reserves of coal. An abundant water supply is a critical factor in coal conversion, and several states with large reserves of thick coal are severely short on water. The geographic position of Missouri's coal reserves, near some of the nation's more important population and industrial growth centers should prove an important incentive for their development despite inherent technical problems.

There is no doubt that Missouri's coal resources will ultimately be utilized. There are steps that can be taken to hasten the advent of the coal conversion industry in the state. Arrangements should be made to test Missouri coal in pilot facilities where possible. Even more importantly, an effort should be made to erect pilot or demonstration plants in Missouri using Missouri coal. Field mapping and delineation of areas of thick coal or areas where multiple seam stripping is possible would help locate blocks of reserves large enough to feed conversion plants.

Although in comparison to coal beds in the Rocky Mountain states, Missouri coal beds are thin; they are not so thin as to discourage interest. At least two billion tons occur in beds 42 inches or more thick and at least four billion tons occur in beds 36 inches or more thick. It is possible to recover beds of such thickness by underground methods. In addition, areas exist in Missouri where rather large areas of strippable coal, some in miltiple beds, average at least 5 feet in thickness. Additional geologic field work, accompanied by drilling, would most certainly delineate large blocks of economically recoverable coal.

Feasibility studies, taking into account availability of coal and water resources, energy markets and needs, the availability of transportation facilities and economic and environmental factors, should proceed erection of demonstration plants. Detailed mapping and sampling of potential coal reserves should accompany the feasibility studies.

CONCLUSIONS

Coal from the Western Interior Coal Region can be a positive factor in enabling the United States to become energy self-sufficient. Missouri, with a coal resource base of 49 billion tons and a recoverable reserve of over 6 billion tons, is in a particularly good position to greatly expand its coal mining industry.

In order for Missouri coal to make a significant contribution in the near future, the following steps must be taken.

(1) Areas of economically recoverable coal must be delineated by field mapping and drilling.

(2) Research on mining plans that will allow economic recovery of thin seams while minimizing environmental degradation must be encouraged.

(3) Research on improving reclamation methods to lower costs while minimizing environmental degradation must be encouraged.

(4) Effective, economical desulfurization methods must be developed by pilot testing on existing or experimental facilities which use Missouri coal.

(5) Construction of coal conversion facilities in the state must be actively encouraged, beginning with pilot or demonstration facilities.

In addition to the above it is suggested that consideration be given to recovering deep coal by insitu gasification.

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A TECHNIQUE FOR IMPROVING STABILITY OF PETROLEUM RESERVOIR SIMULATION MODELS

M.D. Arnold T.C. Wilson A. Herbert Harvey

University of Missouri - Rolla

ABSTRACT

Computational instability may occur in the mathematical simulation of hydrocarbon reservoirs when small inaccuracies in the calculated pressures cause loss of diagonal dominance in the matrix of coefficients. The problem can be resolved by the use of a more precise technique for computation of pressures. However, this stability problem is still troublesome to users of certain types of reservoir simulators. A computational technique which has been found effective in resolving the problem is presented.

INTRODUCTION

The technology of petroleum reservoir engineering was initially based on empiricism and rule-of-thumb generalizations. Reservoir productivity was first predicted almost entirely on the basis of performance of similar reservoirs. This approach was generally satisfactory for estimating the productivity of new oil fields which did not differ markedly from older reservoirs. However, the empirical approach was not adequate for solving any reservoir engineering problems which were substantially outside the realm of past experience. Thus it was soon recognized that new and more versatile techniques were needed for predicting the performance of hydrocarbon reservoirs.

The next significant development in petroleum reservoir engineering might be considered to be the concept of the material balance and the numerous prediction methods which were derived from this concept. Development of these prediction methods was significant, since they provided a means for solving reservoir engineering problems which could not be handled on the basis of past experience with similar reservoirs. However, since these techniques were devised before the advent of the digital computer, it was necessary that certain assumptions be made in order to limit the amount of computation required. Therefore, all of these early material balance methods were formulated with the assumption that rock and fluid properties would not vary from point to point in the reservoir. Similarly, pressures and saturations were generally handled as average values throughout large segments of the hydrocarbon deposit. Although the use of these simplifying assumptions may give realistic results for some hydrocarbon reservoirs, they can also lead to serious errors in the prediction of reservoir performance. Therefore, these early material balance methods have now been largely supplanted by more advanced techniques.

The digital computer has now become the primary tool for modern reservoir engineering work. This type of computer has the capability not only of performing extremely rapid calculations but also of handling very large sets of data. Thus, it is now feasible to calculate the performance of a petroleum reservoir with rock and fluid properties considered to vary with pressure and position, and with saturations and pressures described by gradients which are functions of position and production history. The calculations are too complex to be performed by hand; therefore, they are incorporated in a computer program which is generally called a mathematical simulation model.

The mathematical relationships which comprise the reservoir simulation model include both algebraic equations and partial differential equations (some of which may have variable coefficients). For most problems which are of practical interest, the set of equations is too complex for solution by any known analytical technique. Therefore, the differential equations are converted to finite difference equations so that numerical solution techniques can be employed. These differential equations are written for each element of a reference grid which is used to describe the system under study. This procedure yields a system of equations which can be solved simultaneously by a suitable numerical technique. The convergence properties of some numerical solution techniques currently in use are such that stability problems can arise during a simulation study. One such problem, which leads to instability when the pressure is near the bubble point, is a reversal in algebraic sign of the total compressibility of the rock-fluid system. This is a computational phenomenon and not an actual field occurrence. However, it should be corrected to prevent the generation of computational instabilities which may cause the model to yield erroneous results. The purpose of this paper is to present a method for correcting this compressibility problem.

PRESSURE EQUATION

The pressure equation is basic to any mathematical model of reservoir behavior. The complexity of this relationship, which describes pressure as a function of position and time, can vary considerably. For a one-dimensional, one-phase slightly compressible system the equation may be written*

$$\frac{\partial^2 P}{\partial x^2} = \frac{\phi \mu c}{k} \frac{\partial P}{\partial t} \qquad (1)$$

* Symbols are defined in the Nomenclature.

The solution of equation (1) causes no stability problems because the equation contains constant coefficients of the pressure derivatives.

A more realistic pressure equation for a hydrocarbon reservoir is given by

$$(B_o - B_g R_s)\nabla\cdot T_o \nabla\Phi_o + B_g \nabla\cdot T_o R_s \nabla\Phi_o + B_g \nabla\cdot T_g \nabla\Phi_g + B_w \nabla\cdot T_w \nabla\Phi_w = h\phi(c_r + S_w c_w - \frac{S_o}{B_o}\frac{dB_o}{dP} - \frac{S_g}{B_g}\frac{dB_g}{dP} + \frac{S_o B_g}{B_o}\frac{dR_s}{dP})\frac{\partial P}{\partial t} + q' \quad (2)$$

This mathematical relationship accounts for variable rock and fluid properties for three mobile fluid phases, and for two- or three-dimensional flow. The nonlinearity of equation (2) requires that special solution techniques be employed in order to maintain stability of the computations. This equation is the basic component of the model in which the compressibility sign reversal problem was studied.

When equation (2) is written as a finite difference, the following result is obtained:

$$(A_{i,j}P_{i-1,j} + B_{i,j}P_{i+1,j} + C_{i,j}P_{i,j} + D_{i,j}P_{i,j-1} + E_{i,j}P_{i,j+1})^{n+1} = F_{i,j} \quad (3)$$

where the superscript denotes the n + 1 time level, and the subscripts i and j identify the x and y coordinate positions, respectively.

The coefficients A, B, D, and E which appear in equation (3) are composite terms containing transmissibilities and material balance terms. These are defined in the Appendix. The term F and the coefficient C are defined below since they contain the overall compressibility term and must be adjusted in order to correct the compressibility problem.

$$F_{i,j} = - G_{i,j} P^n_{i,j} + H_{i,j} \quad (4)$$

$$G_{i,j} = \left(\frac{h\phi}{\Delta t}\right)_{i,j} \left(c_r + S_w c_w - \frac{S_o}{B_o}\frac{dB_o}{dP} - \frac{S_g}{B_g}\frac{dB_g}{dP} + \frac{S_o B_g}{B_o}\frac{dR_s}{dP}\right)_{i,j} \quad (5)$$

and

$$C_{i,j} = - A_{i,j} - B_{i,j} - D_{i,j} - E_{i,j} - G_{i,j} \quad (6)$$

The authors customarily describe the fluid properties employed in these equations by means of polynomial expressions. Special attention must be given to maintenance of accuracy of these expressions near the bubble point pressure. Derivatives of the fluid properties are computed by differentiation of the polynomials.

COMPRESSIBILITY REVERSAL PROBLEM

The compressibility sign reversal problem often arises in simulation models which do not use computational techniques which calculate pressures to a high degree of accuracy. Small errors in the pressure computations will be strongly reflected in the saturation calculations and in loss of material balance accuracy. Although these errors may be too small to be of practical importance in predicting reservoir pressure, they may still cause computational instability at pressures near the bubble point.

The compressibility problem will occur when errors in the computation cause the overall compressibility term $G_{i,j}$ to be calculated with an incorrect algebraic sign. This condition causes the loss of diagonal dominance in some rows of the matrix of coefficients which is derived from equation (3).

The requirement for maintaining diagonal dominance in the matrix of coefficients is that for all i and j

$$|C_{i,j}| \geq |A_{i,j}| + |B_{i,j}| + |D_{i,j}| + |E_{i,j}| \quad (7)$$

This relationship is not a necessary criterion for convergence. However, loss of diagonal dominance often requires a substantial reduction in time step size for maintenance of computational stability. Thus the retention of diagonal dominance is desirable from a practical standpoint.

COMPRESSIBILITY REVERSAL CORRECTION

In order to overcome the compressibility reversal problem it is necessary to restore the loss of diagonal dominance which results from a negative value of the compressibility term $G_{i,j}$. This negative term reduces $C_{i,j}$ in accordance with equation (6), so that inequality (7) is not satisfied.

In order to illustrate how the compressibility reversal problem can arise, it is useful to examine the algebraic sign of the various pressure coefficients. The coefficients $A_{i,j}$, $B_{i,j}$, $D_{i,j}$, and $E_{i,j}$ are always positive numbers. Normally, $G_{i,j}$ is also positive and inequality (7) is satisfied. In particular, the quantity $G_{i,j}$ will not become negative above the bubble point pressure since $G_{i,j}$ will contain no negative terms. However, at pressures below the bubble point, the quantity $(-dB_o/dP)$ will always be negative since gas evolution causes the reservoir oil to shrink when the pressure is reduced. This existence of a negative term in $G_{i,j}$ suggests that it can become negative. In particular, $G_{i,j} < 0$

when $\frac{S_o}{B_o}\frac{dB_o}{dP} > (c_r + c_w S_w - \frac{S_g}{B_g}\frac{dB_g}{dP} +$

$$\frac{S_o B_g}{B_o}\frac{dR_s}{dP}) \qquad (8)$$

This condition is especially likely to occur for reservoir fluids that have a high bubble point pressure. Since B_g is small at high pressures, the magnitude of B_o' may exceed the product $B_g R_s'$ for these fluids. Then $S_g B_g'/B_g$ should offset the negative terms in the total compressibility expression, since rock and water compressibilities are relatively insignificant below the bubble point. However, inaccuracy in the material balance may prevent computed gas saturation from increasing as rapidly as it should, and thus allow the negative value of B_o' to assume undue significance in the total compressibility term at pressures slightly below the bubble point.

Occurrence of the compressibility reversal phenomenon frequently coincides with the use of a time step which encompasses the transition from pressures above the bubble point to pressures below the bubble point. The problem seldom persists for more than a few time steps. However, when the problem does occur it may cause the calculation to become unstable.

The problem can be resolved by writing equation (3) in a manner which retains diagonal dominance by precluding the possibility of a negative system compressibility term. Note that equation (3) may be written as

$$W_{i,j} + C_{i,j} P^{n+1}_{i,j} = F_{i,j} \qquad (9)$$

where

$$W_{i,j} = A_{i,j} P^{n+1}_{i-1,j} + B_{i,j} P^{n+1}_{i+1,j} + D_{i,j} P^{n+1}_{i,j-1} + E_{i,j} P^{n+1}_{i,j+1} \qquad (10)$$

Expanding $C_{i,j}$ and $F_{i,j}$ in equation (9) yields

$$W_{i,j} + (-A_{i,j}-B_{i,j}-D_{i,j}-E_{i,j}-G_{i,j}) P^{n+1}_{i,j} = -G_{i,j} P^{n}_{i,j} + H_{i,j} \qquad (11)$$

This equation may be rearranged to obtain

$$W_{i,j} + (-A_{i,j}-B_{i,j}-D_{i,j}-E_{i,j}-G'_{i,j}) P^{n+1}_{i,j} + \left(\frac{h\phi}{\Delta t}\frac{S_o}{B_o}\frac{dB_o}{dP}\right)_{i,j} P^{n+1}_{i,j} = - G'_{i,j} P^{n}_{i,j} + \left(\frac{h\phi}{\Delta t}\frac{S_o}{B_o}\frac{dB_o}{dP}\right)_{i,j} P^{n}_{i,j} + H_{i,j} \qquad (12)$$

where

$$G'_{i,j} = \frac{(h\phi)_{i,j}}{\Delta t} \left(c_r + S_w c_w - \frac{S_g}{B_g}\frac{dB_g}{dP} + \frac{S_o B_g}{B_o}\frac{dR_s}{dP}\right)_{i,j} \qquad (13)$$

Rearranging equation (12)

$$W_{i,j} + (-A_{i,j}-B_{i,j}-D_{i,j}-E_{i,j}-G'_{i,j}) P^{n+1}_{i,j} = -G'_{i,j} P^{n}_{i,j} + H_{i,j} - \left(\frac{h\phi S_o}{B_o}\right)_{i,j} \left(\frac{dB_o}{dP}\frac{P^{n+1} - P^{n}}{\Delta t}\right)_{i,j} \qquad (14)$$

Considering the final term enclosed in parentheses in equation (14), we may note that

$$\frac{dB_o}{dP}\frac{P^{n+1} - P^{n}}{\Delta t} \approx \frac{dB_o}{dP}\frac{\partial P}{\partial t} \qquad (15)$$

and that

$$\frac{dB_o}{dP}\frac{\partial P}{\partial t} = \frac{dB_o}{dt} \qquad (16)$$

Thus we may employ a conventional finite difference approximation of $\frac{dB_o}{dt}$ and write equation (14) as

$$W_{i,j} + (-A_{i,j}-B_{i,j}-D_{i,j}-E_{i,j}-G'_{i,j})P^{n+1}_{i,j} = -G'_{i,j} P^{n}_{i,j} + H_{i,j} - \left(\frac{h\phi S_o}{B_o}(B^{n+1}_o - B^{n}_o)/\Delta t\right)_{i,j} \qquad (17)$$

In order to employ the above relationship when instability might occur, it is convenient to define revised matrix elements $F''_{i,j}$ and $G''_{i,j}$ as follows:

$$G''_{i,j} = \frac{(h\phi)_{i,j}}{\Delta t} (c_r + S_w c_w - \frac{\alpha S_o}{B_o}\frac{dB_o}{dP} -$$

$$\frac{S_g}{B_g}\frac{dB_g}{dP} + \frac{S_oB_g}{B_o}\frac{dR_s}{dP})_{i,j} \qquad (18)$$

and

$$F''_{i,j} = - G''_{i,j}\, P^n_{i,j} + H_{i,j} +$$

$$(\alpha-1)(h\phi)_{i,j}\left(\frac{S_o}{B_o}(B_o^{n+1} - B_o^n)\right)_{i,j}/\Delta t \qquad (19)$$

where $\alpha = 1$ when $G_{i,j} > 0$

$\alpha = 0$ when $G_{i,j} \leq 0$

and where $F''_{i,j}$ replaces $F_{i,j}$ in equation (3) and $G''_{i,j}$ replaces $G_{i,j}$ in equation (5).

The procedure described above introduces a time derivative which is less accurate than the conventional approach, since it requires that

$B^{n+1}_{o_{i,j}}$ be extrapolated from $B^n_{o_{i,j}}$. However,

this approximation is employed only when the more conventional technique would become inadequate because of loss of diagonal dominance.

CONCLUSION

Tests have shown that the procedure presented here will allow a petroleum reservoir simulation to maintain stability through the bubble point pressure without substantial reduction in time step size and without significant loss in accuracy. The technique is recommended for use with simulation models which are sufficiently accurate for solving the problem under study, but which tend to be unstable at the bubble point.

NOMENCLATURE

B = Formation volume factor

c = Compressibility

g = Gravitational acceleration

h = Thickness

k = Permeability

n = Time level, superscript

P = Pressure

q = Production rate

R = Gas/oil ratio

S = Saturation

t = Time

T = Transmissibility

x = Directional coordinate

y = Directional coordinate

z = Depth below datum plane

μ = Viscosity

ρ = Density

ϕ = Porosity

Φ = Potential

Subscripts:

c = Capillary

g = Gas

gf = Free gas

i = Index number for x ccordinate

j = Index number for y coordinate

o = Oil

p = Phase

r = Rock

s = Solution

w = Water

APPENDIX

Definition of Matrix Terms

$$A_{i,j} = \frac{2}{\Delta x_i(\Delta x_i + \Delta x_{i-1})} \left((B_{o_{i,j}} - B_{g_{i,j}} R_{s_{i,j}} + B_{g_{i,j}} R_{s_{i-\frac{1}{2},j}}) T_{o_{i-\frac{1}{2},j}} + B_{g_{i,j}} T_{g_{i-\frac{1}{2},j}} + B_{w_{i,j}} T_{w_{i-\frac{1}{2},j}} \right)$$

$$B_{i,j} = \frac{2}{\Delta x_i(\Delta x_{i+1} + \Delta x_i)} \left((B_{o_{i,j}} - B_{g_{i,j}} R_{s_{i,j}} + B_{g_{i,j}} R_{s_{i+\frac{1}{2},j}}) T_{o_{i+\frac{1}{2},j}} + B_{g_{i,j}} T_{g_{i+\frac{1}{2},j}} + B_{w_{i,j}} T_{w_{i+\frac{1}{2},j}} \right)$$

$$H_{i,j} = (B_o - B_gR_s)_{i,j}\Delta_x^2(T_o\rho_o gz)_{i,j} + B_{g_{i,j}}\Delta_x^2(T_oR_s\rho_o gz)_{i,j} + B_{g_{i,j}}\Delta_x^2(T_g\rho_g gz)_{i,j} +$$

$$B_{w_{i,j}} \Delta_x^2 (T_w \rho_w gz) + (B_o - B_g R_s)_{i,j} \Delta_y^2 (T_o \rho_o gz)_{i,j} +$$

$$B_{g_{i,j}} \Delta_y^2 (T_o R_s \rho_o gz)_{i,j} + B_{g_{i,j}} \Delta_y^2 (T_g \rho_g gz)_{i,j} +$$

$$B_{w_{i,j}} \Delta_y^2 (T_w \rho_w gz)_{i,j} + B_{w_{i,j}} \Delta_x^2 (T_w P_{c_{o-w}})_{i,j} +$$

$$B_{g_{i,j}} \Delta_x^2 (T_g P_{c_{o-g}})_{i,j} + B_{w_{i,j}} \Delta_y^2 (T_w P_{c_{o-w}})_{i,j} +$$

$$B_{g_{i,j}} \Delta_y^2 (T_g P_{c_{o-g}})_{i,j} + q'$$

where Δ_x^2 and Δ_y^2 are finite difference operators which imply second derivatives with respect to x and y, respectively.

The transmissibilities and potentials for each phase p, and the flow term, q', are defined by

$$T_p = \frac{khk_{rp}}{B_p \mu_p}$$

$$\Phi_p = (P - \rho_p gz + P_{c,o-p})$$

and

$$q' = \frac{q_o B_o + q_w B_w + q_{gf} B_g}{\Delta x \Delta y}$$

The matrix coefficients $D_{i,j}$ and $E_{i,j}$ are identical to $A_{i,j}$ and $C_{i,j}$, respectively, except for the replacement of Δx by Δy and the interchange of the i and j subscripts.

VI - ENERGY SYSTEMS

CHAIRMAN:
J. DERALD MORGAN

POWER TRANSMISSION TECHNOLOGY FOR THE 1980-1990 TIME PERIOD

T. H. Lee
General Electric Company
Philadelphia, Pennsylvania

It is a great pleasure for me to have this opportunity to present to you a subject that is very close to my heart - future transmission systems. Electrical demand in the U.S. is doubling every ten years. While the electric growth capacity characteristics are being questioned for the future, the best estimates are that this will continue at least through the 1990's.

Load tends to be concentrated in cities and historically generating plants were located in cities. Environmental considerations for fossil plants are tending to locate them away from cities and the trend is expected to continue. Reluctance to accept nuclear plants near larger cities results in locating these out of cities. Transmission will become increasingly important not only to bring energy from remote plants to the cities but to provide interconnections between areas for improved reliability in emergencies and to take advantage of area diversity in demands.

When we look at our crystal ball and try to find out how transmission systems will be designed in the year of 1990, we must try to answer several questions:

1) What is the next level of transmission voltage?

2) Is it going to be overhead or underground?

3) Is it going to be AC or DC?

4) What are the technological advances we can predict for transmission equipment?

5) How about the non-conventional ideas of power transmission such as microwaves and solar energy?

6) How do we plan for the transmission system in the year 1990?

1. Next Voltage Level

In 1889, the first alternating current transmission in the United States went into service at Oregon City. Power at 4000 volts was transmitted 13 miles to Portland, Oregon. During the next 24 years significant progress was made and by 1913 transmission voltages were up to 150 kV.

The evolution of transmission voltage continued increasing to 165 kV in 1922, 230 kV in 1923, 287 kV in 1935, 345 kV in 1953, 500 kV in 1965 and 765 kV in 1969. With the increasing demand for electric power, we are now led to the threshold of ultra-high voltage (UHV), voltages at 1000 kV and above.

In Pittsfield, Mass., the General Electric Company has been conducting a research project under the sponsorship of the Electric Research Council, and more recently, The Electric Power Research Institute. This is the Project UHV and its purpose is to find out what are the problems and how to solve these problems if we have to design transmission systems at voltages as high as 1500 kV. Perhaps you might be interested in some of the surprises in the insulation system design as we move from 345 kV to higher levels.

At 345 kV, lightning used to be the most important design criteria, i.e., if your insulation system can withstand the lightning voltage that it is supposed to, then it can withstand any other sources of overvoltage the system may impose upon it. Lightning is a very fast rising voltage wave, rising to its peak in a matter of a microsecond and decays in some tens of microseconds. When we move to 500 kV, we found that a much slower rising voltage caused by the operation of circuit breakers is a much more difficult duty. This is the so-called switching surges. These surges rise to the peak in a time period of several hundred microseconds. Switching surges have peculiar characteristics like shown in Figure 1. It does not always cause a breakdown to ground which is closest to the source of high voltage. Here instead of breakdown to the nearest ground which is 26 ft. away it chose to arc over to a trailer and trees which are 80 to 150 ft. away.

At 765 kV we find that may be switching surge is no longer the most severe duty. Instead, the contamination on insulators may prevent them from withstanding normal system voltages. If we can design systems to withstand that, then lighting and switching surges may be nothing to worry about.

We are finding other new problems at these ultra-high voltages. For example, in foggy weather UHV transmission lines may emit audible noise like fire crackers. If a truck is under a UHV line it may be charged up to a high enough voltage so that anyone who touches it may get a shock. All these problems require R & D to solve and we are working very hard on them. It is probably safe to say that 1100 or 1200 kV will be technically feasible very shortly and voltages as high as 1500 kV may prove to be feasible.

As we think about the next voltage level, though, we must face a rather important question. In our country, we really have two power systems. One consists of the voltage levels of 115, 230 and 500 kV and the other one - 168, 345, 765 kV. For every system voltage level, we must conduct R & D for system design and equipment development. This

Figure 1. Switching Surge Test on 1500 kV Transformer Bushing

costs money. For the next level, wouldn't it be wise if we have a single voltage level such as 1250 or 1300 instead of going merrily the same way as before: 1000 kV on top of 500, 1500 kV on top of 765? But this calls for some statesmanship or better yet, the elimination of some of the one-upmanship to do it.

2. Overhead or Underground

Now the second question: Is it going to be overhead or underground?

To put this in perspective, today there are about 250,000 miles of overhead transmission lines at 115 kV or higher in the United States but only about 1800 miles of underground cables at voltages of 115 to 345 kV. The pertinent reason for this difference is the relatively high cost of underground transmission.

In an overhead transmission system, insulation is obtained by porcelain or other insulators at supporting structures and sufficient clearance in air. Heat losses in the conductors are dissipated readily to the air.

Today's conventional high voltage cables consist of a conductor insulated with oil impregnated paper tapes and covered by a metallic ground sheath.

Where several feet of clearance provided insulation for an overhead system, insulating paper tapes with a total radial thickness of the order of an inch must provide equivalent insulation for an underground cable. At 500 kV for example, the cable insulation thickness is about 1.25" compared to 10 to 11 feet air clearance at supporting towers of an overhead system. Where overhead conductor losses are readily dissipated to air, in the underground system losses must be dissipated through the cable insulation and then through the earth, both relatively good heat insulators. To prevent deterioration of the organic insulation by temperature, an underground conductor must be operated at a considerably lower current than the equivalent conductor size in an overhead system.

In an underground AC system, there are additional losses in the insulation which must be dissipated and the charging current of the cable limits the length which can be used without compensation; an expensive addition with environmental impact.

To provide a reliable high voltage cable, careful control must be exercised in material selection, manufacturing processes and installation. Cable splicing must be performed in a clean, low humidity atmosphere.

Excavation and backfill processes for cable installation are costly particularly in areas with considerable rocks.

Underground installation in open country is not without environmental impact since right of ways in the width order of 50 to 100 feet must be cleared to permit installation and future maintenance.

Underground cables are in use today at 345 kV and recently completed tests at the EPRI Waltz Mill test facility have confirmed the availability of a 550 kV cable. Underground transmission is costly, ranging from 10 to 20 times the cost of overhead. The situation is much different than that for the lower voltage distribution system where undergrounding may be done at 1.5 to 2.0 times greater cost than for overhead.

Where it is possible to obtain overhead right of ways at reasonable cost or to develop utility corridors, overhead will always be less expensive than underground transmission. However, environmental conditions or prejudices which force generating plants out of cities and which ban overhead lines on scenic or historic areas will result in increasing use of underground transmission, despite higher costs.

Recognizing the need for lowering the cost of underground transmission and for providing for the higher capacity circuits that will be required in the 1990's, the Electric Power Research Institute has an active program for research and development in underground transmission. Since projected costs of new systems are not always realistic until research and development is complete, work is underway or planned for different types of systems which may serve the same circuit capacity requirements. This assures an ultimate selection of the most economic system for the required capacity.

I might mention here that some proposed systems appear to be economical for circuit capacities considerably higher than presently acceptable for system reliability but which are likely to be acceptable in the 1990's when unit generator capacity and system loads will have increased markedly.

Programs completed or actively in progress under the direction of the Electric Power Research Institute include:

1. The construction and operation of a test station by Westinghouse at Waltz Mills, Pa. for testing various underground transmission systems up to 1100 kV AC.

2. Increasing capacity of conventional cable circuits by forced cooling, including the use of refrigeration.

3. Development of synthetic paper and synthetic laminar cables for the purpose of decreasing insulation losses and thus increasing ratings at present voltage levels and making possible at least an 800 kV AC cable.

4. Development of compressed gas insulation systems. Several short sections of such a system have been commercially installed at 345 kV. They are a cylindrical aluminum conductor supported by insulating spacers in a larger aluminum sleeve having an outer corrosion protection coating. The space between the inner conductor and outer cylinder is filled with an insulating gas under pressure. SF_6 at a nominal 22 psig has been used.

   Three single phase assemblies constitute a three phase system. These systems have the advantage of materially reducing charging current for AC operation, are relatively simple in construction and have a minimum of accessory equipment. However, present size and installed cost are a disadvantage. Capacities of 1000 to 2500 MVA are readily obtainable and forced cooling would provide higher capacities. While systems have been designed to 345 kV, satisfactory operation is expected at voltage up to 1000 kV. Research continues on three phase systems, spacer insulation, gas mixtures and higher gas pressures.

5. Study of the breakdown mechanism in ex-

truded cross linked polyethylene cable. Extruded cables are simpler to manufacture. Such cables are on test at 138 kV at Waltz Mill. Whether their use can be extended to higher voltages will depend on a better understanding of the mechanism at failure in extruded materials.

6. Cable Joint Simplification. A very desirable project to reduce the time and conditions under which splices presently have to be made.

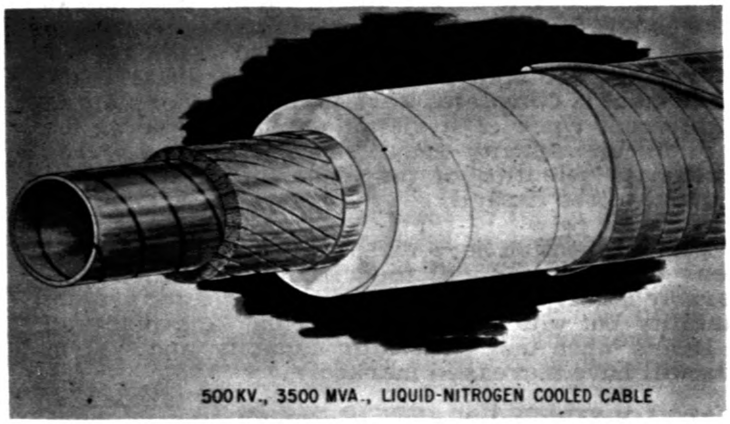

Figure 2. 500 kV, 3500 MVA, Liquid-Nitrogen Cooled Cable

7. Resistive Cryogenic Transmission System. A resistive cryogenic AC transmission system takes advantage of the substantial reduction in resistivities of metals such as copper or aluminum at very low temperatures and consequently reduces the ohmic losses in a transmission system. G.E. completed a project for Electric Research Council which resulted in the manufacture of a 500 kV cable design (Figure 2) using an aluminum conductor cooled by liquid nitrogen and insulated with Tyvek tapes. The prototype tested by Phelps Dodge Wire & Cable Co. withstood rated voltage but failed at 20% overvoltage. A three phase cable in an 18 inch pipe has been designed to carry 3500 megavolt-amperes at a system voltage of 500 kV. (Figure 3) An extension to this contract has been authorized by EPRI for the development of an improved insulation

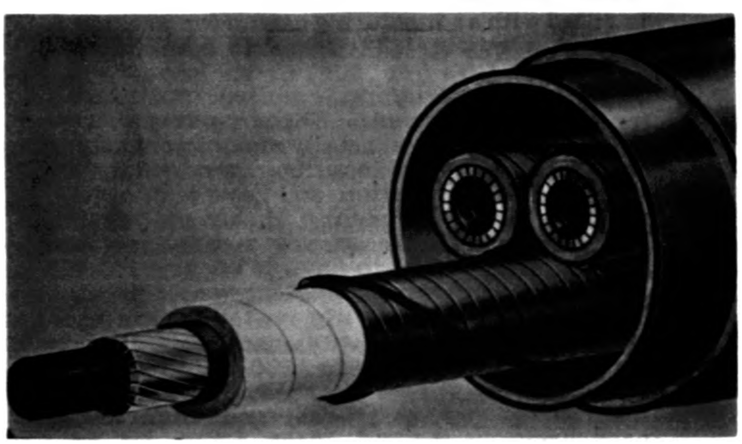

Figure 3. 3-Phase, 500 kV, 3500 MVA, Liquid-Nitrogen Cooled Cable

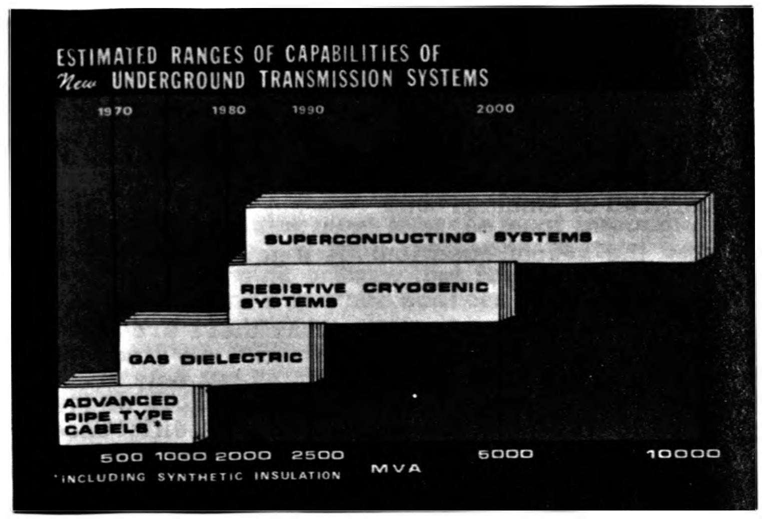

Figure 4

system and demonstration of its suitability and long term stability. The overall objective is to make available a commercial system by the 1980's in the 3000 to 4000 MVA range. Other research organizations are studying cryogenic insulation materials and the use of vacuum insulation systems.

8. Super Conducting Cable System. A super conducting cryogenic transmission system utilizes the properties of certain metals which have zero resistance below a certain low transition temperature. Research by the Linde Division of Union Carbide for the Electric Research Council has shown that niobium has sufficiently low AC losses to suggest its use for an AC transmission system. A further EPRI project assigned to the same company has the objective of demonstrating the feasibility of building an economic system for the transfer of power in the order of 1,000 to 10,000 MVA at voltages in the 138 to 345 kV level. This system envisions the use of niobium plated copper conductors supported on the dielectric spacers with liquid helium at about 4° K as both the electrical insulating and cooling medium. A thermal insulating system combining the use of high vacuum and super insulation is necessary. Refrigerating plants would be installed approximately every five miles. Pre-fabricated transmission sections of 40 to 60 feet are planned.

Improvements in very low temperature thermal insulation techniques and in the efficiency of high capacity cryogenic refrigerators would be very useful in reducing cryogenic system costs.

Different types of underground systems vary widely in power handling capacity. Estimated capacity ranges of several systems are shown in Figure 4. Costs of underground systems vary with the physical characteristics of the system, the capacity to be transferred, elevation changes, length of circuit and type of terrain. Comparisons should be made for a specific installation. An estimate of the cost range

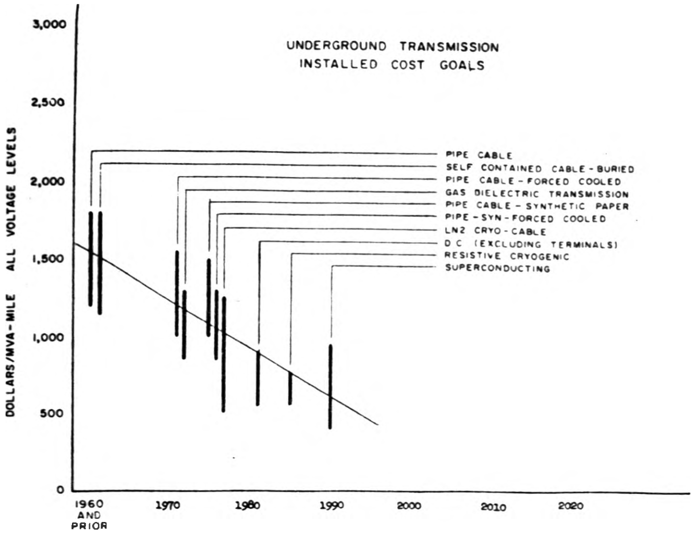

Figure 5

for various types of underground transmission systems is given by Figure 5. It should be emphasized that these are the best present estimates and involve some systems which have not yet been proved commercially feasible.

Other underground developments expected to be pursued include systems for mapping existing underground structures by an appropriate survey from the street surface and improved installation methods. The first would provide savings in planning a new underground system and the second would hopefully reduce to some extent the very costly procedure of excavating and backfilling for underground systems.

The June 1971 report of the R&D Goals Task Force to the Electric Research Council recommends research and development expenditures of $344,000,00 for AC underground transmission, $85,000,000 for AC overhead transmission and $116,000,000 for DC transmission through the year 2000.

The recommended expenditures for AC underground transmission should provide commercially feasible designs to transmit desired capacities as required in this period at the most economical cost. It is not to be expected the underground costs will be as low as overhead costs where overhead right of ways are feasible. Overhead systems will continue to be the major transmission mode for AC through this period unless the public decides that the benefits for putting electrical transmission underground far outweigh other social improvements which might be made with the savings involved in constructing overhead transmission.

3. AC or DC

The third question is: Is it going to be AC or DC?

It has been recognized for a long time that basically DC transmission lines cost less than AC for the same power to be transmitted. But AC has many advantages. It is easier to generate AC, its voltages can be stepped up or down at will; and you can tap into an AC line anytime and at any place that you wish. Thus, for many years, DC was only considered either for very long distance point-to-point transmission or some underwater crossings where the savings in cable cost are significant. Even though for these applications, special conversion equipment had to be developed.

The high voltage mercury arc rectifier developed by ASEA in Sweden represented one of the major advances in HVDC transmission. Underwater crossings first went in on the island of Gotland and subsequently we found more applications such as the cross channel link between England and France, lines to tie two different frequencies together in Japan, and finally the major DC line that runs 800 miles from Dalles in Oregon to Los Angeles.

As experience was mounting on the operation of HVDC systems, we also find many other advantages of DC. They can help to stabilize AC systems during transient disturbances, they can help to limit the short circuit current in the power systems, they can tie asynchronous systems together and they can be controlled in terms of the amount of power to be transmitted in a predetermined way. Interest in DC started to mount in the '60's.

At about the same time that decision on the West Coast Intertie was made, we in the General Electric Company had a major decision to make. Should we extend our mercury arc technology for industrial applications to HVDC transmission or should we leapfrog the state of art with a new technology. We were impressed with how rapidly semi-conductors were displacing mercury arc rectifiers in industrial applications. Even though, the power semiconductors were not large enough in voltage and power ratings to make them attractive for HVDC application, we had faith that technology will continue to advance to the point that it will displace mercury arc rectifiers in HVDC applications just like they did in industrial applications. Therefore in 1964, we started a program to develop solid state HVDC conversion system, I might add that amid pessimism in the entire industry, domestic and abroad, of the future of silicon controlled rectifiers for HVDC. Eight years later, I am pleased to report that the entire industry is going our way. SCR's now are the facts of life for DC transmission.

Let me go through with you the progress we have made. We developed a 40 MW back-to-back system (Figure 6) and ran it in our laboratory for some time. Then we built and tested a 200 kV valve in 1967. (Figure 7) This valve represented a single unit as high in power rating as we anticipate needing and it is still the largest valve that has ever been tested.

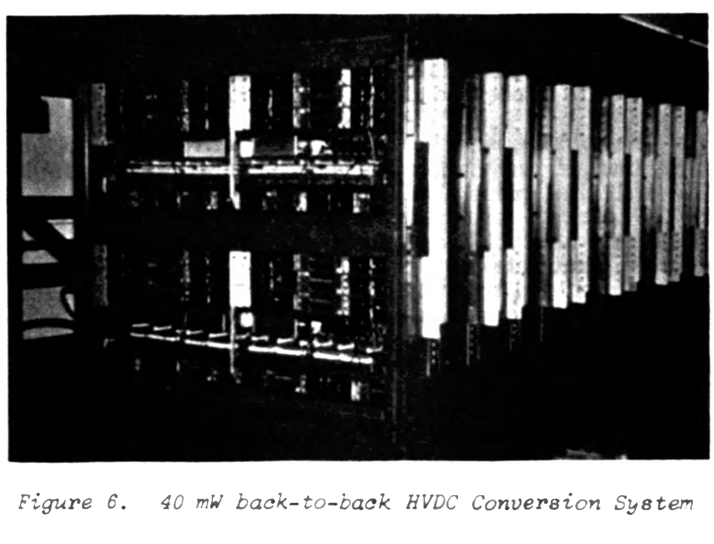

Figure 6. 40 mW back-to-back HVDC Conversion System

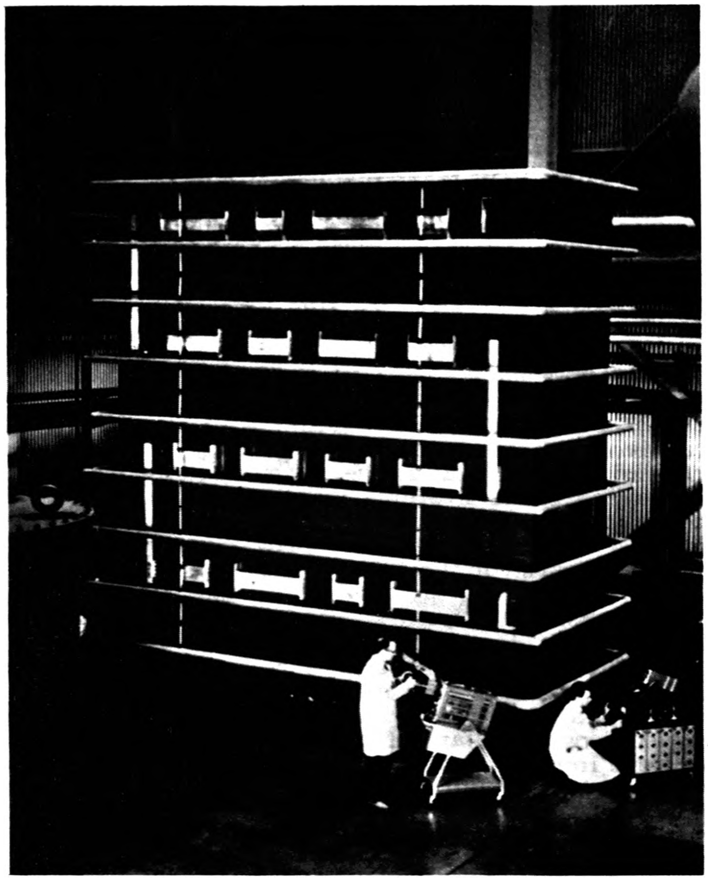

Figure 7. HVDC Conversion System 200 kV Valve

in 1967. (Figure 7) This valve represented a single unit as high in power rating as we anticipate needing and it is still the largest valve that has ever been tested.

We were very pleased to receive an order from the New Brunswick Electric Power Commission in 1969 for a 320 MW asynchronous tie between the power system of Quebec and New Brunswick. In 1972 we energized the World's first semiconductor HVDC system at Eel River, Canada, (Figure 8) and for the first six months, it had an availability of 98.5%, an unheard of record in HVDC history. Here we were benefited from the experience we had in applying the quantitative reliability techniques developed for space and miliary industries.

In working on HVDC systems, we recognized the fact that if we can tap a DC line the usefulness of DC will be greatly enhanced. To do this, we need HVDC circuit breakers. But there was no HVDC breaker available anywhere. The reason is, of course, that this is a very difficult job technically, so we decided to tackle the problem. A few years ago, we developed an 80 kV DC circuit breaker to demonstrate a principle. (Figure 9) Since then, we found a very interesting application for this principle. M.I.T. was involved in thermonuclear fusion research under the sponsorship of AEC. They needed a very fast HVDC switching device to divert current out of a superconducting coil to induce a voltage to pinch the plasma to temperature in the order of hundreds of million degree centigrade for

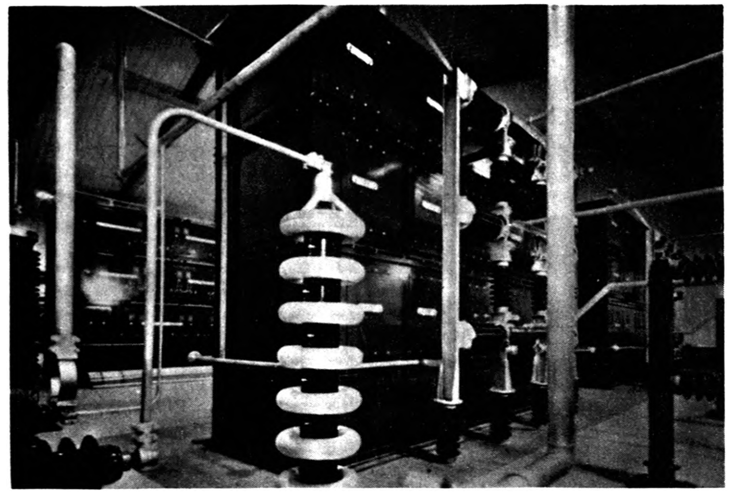

Figure 8. Valve Hall - 320 mW HVDC System at Eel River, Canada

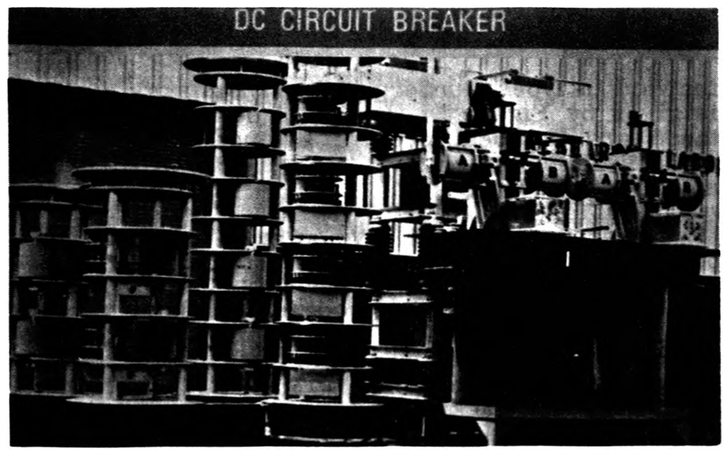

Figure 9. 80 kV - DC Breaker

fusion reaction. We produced such a device for them utilizing the same principle. We are now ready to build HVDC circuit breakers at any practical rating that our power systems may require.

Looking at the future of DC then, we can see tapped lines. We can see much lower conversion costs; we can see compact DC conversion terminals which will make the DC substation much smaller; we can see lower cost DC cables which make it economical to transmit power from a remote generation site to a metropolitan city via the underground route, and we can see DC to be a key factor in trying many power pools together in our country. But for laymen, the question is often asked: Will DC replace AC? I think the answer is no. Our transmission lines, in general, are not that long, 200 miles on the average. We already have a strong AC system. Thus, DC will always be, in my opinion, a complement to our AC system but I believe its usefulness will be ever increasing.

4. Technological Advances

The fourth question is a natural one: Will the equipment needed be available? What are the technological advances that we can expect? To answer this

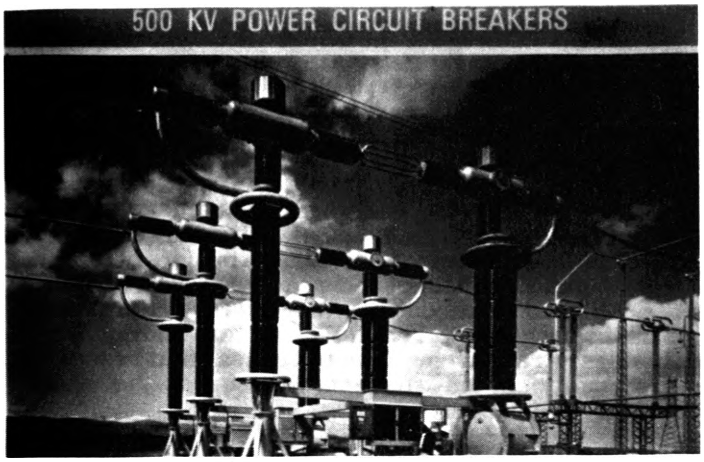

Figure 10. 500 kV Air Blast Circuit Breaker

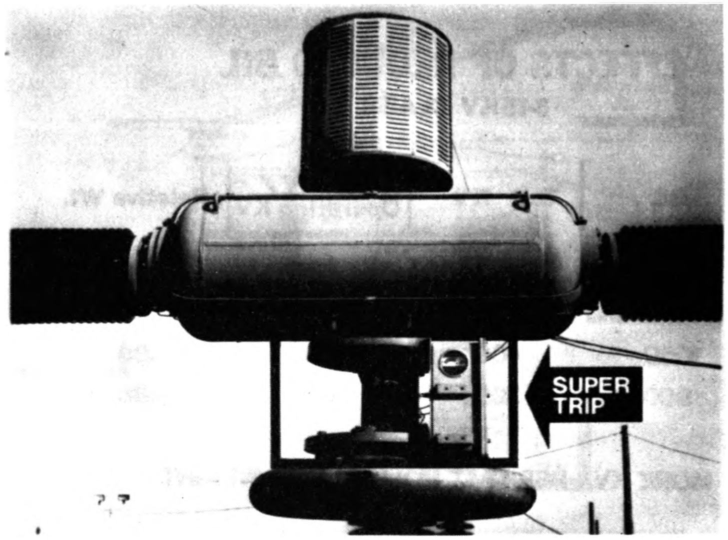

Figure 11. "SuperTrip" - A Device for converting a standard 2-cycle, 550 kV Breaker to give 1 cycle performance

question, we must first of all recognize the fact that our transmission system has grown in an evolutionary way. So has the equipment for that system. Certainly, once in a while, some revolutionary changes take place, like nuclear energy, like gas turbines, like solid state HVDC. But for the next twenty years, it is probably safe to say that evolutionary growth will take care of most of our needs. Let me mention a few examples:

The evolution of Circuit Breakers has been most interesting in that they have not only had to keep pace with the increasing voltages and capacities of transmission systems but, with the growing demand for more system stability, have become more sophisticated.

Additional stability margins can be achieved by using faster breakers and independent pole switching of the circuit breaker. In the latter approach, the closing and tripping control for each breaker pole is independent of the other poles. With this arrangement, a single phase, line-to-ground fault can be opened and reclosed while the unaffected poles remain closed thus reducing system disturbances. Since experience has shown that breaker failures usually involve only one pole of a breaker, independent pole tripping does provide decided advantages.

It is well known that from a system stability standpoint it is desirable to get rid of short circuits as promptly as possible. About 40 years ago the industry began to demand higher speed breakers than were available. Since that time breaker interrupting ratings have been progressively reduced from 20 cycles to 12 cycles in 1930, to 8 cycles in 1933, to 5 cycles in 1938, to 3 cycles in 1944 and to 2 cycles in 1961. We have now taken another step in the evolution of breaker interrupting time. While our air-blast interrupter is available at 2 cycles for any rating of transmission voltage breaker, we have developed, under a contract for BPA, a means of converting the standard 550 kV breaker (Figure 10) to give one cycle performance. The device that makes this possible is termed a "Super-trip" because of its ultra-high speed and the fact that it is superimposed on a standard breaker. (Figure 11) The converter will be package mounted just below the interrupter tank.

Let us review just for a few minutes the advances which have been made in protecting our power systems against lightning and overvoltages. In 1890, the first commercial lightning arrester was introduced. In 1930, thyrite was invented. This was a great step in protection against lightning. However, it was not until 1954 when we were able to extend the application to protection against other types of overvoltages with the introduction of magne valve arresters. Since that time, there has been a steady improvement in the protection level, in the energy they can dissipate and in the overvoltage handling capability.

The advances in arresters had a tremendous influence on the size, weight and dimension of power transformers. Let's look for a moment at a cutaway of a transformer. (Figure 12) The area which we refer to as the core window, for typical high voltage power transformers, may consist of 90% insulation and 10% copper. If one can attain an improvement of 10% in

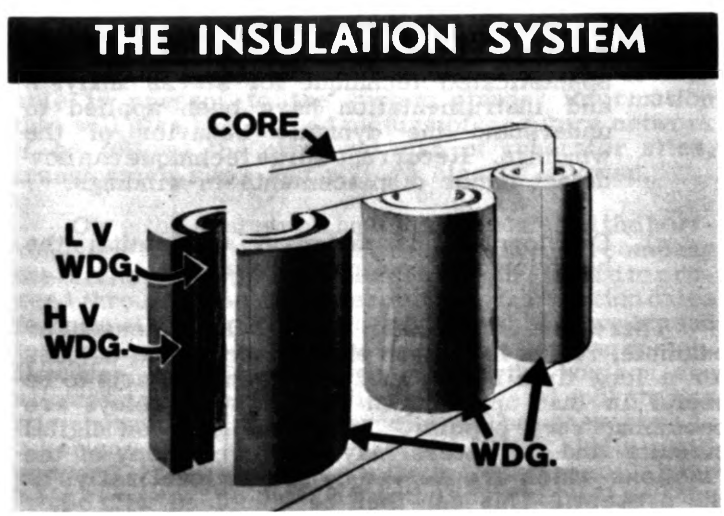

Figure 12. Cutaway view of Transformer

EFFECTS OF REDUCED BIL

345 KV CLASS

BIL	Test KV	Test KV / Operating KV	Relative Wt.
1300	575	2.75	1.00
1175	520	2.50	.94
1050	460	2.20	.90
900	395	1.90	.86

MORE KVA PER UNIT VOLUME AND WEIGHT

Figure 13.

insulation effectiveness, copper space would increase to 19%. This suggests that a much higher rating can be assigned for the same size. Figure 13 shows the effect of reduced BIL alone on the weight of typical 345 kV transformers.

In the last 20 years, the power rating of transformers has increased by a factor of 10. Even with the improvement in weight per kVA, we are still facing a shipping problem. Imagine how bad the problem would be if we had not done the R&D on insulation systems and arresters.

Today, one of the most important considerations to power transformers is reliability. Let us take a quick glance at the R&D work to improve the reliability of transformers.

a) Great advances have been made in corona detections. Testing requirements are becoming more severe as we learn more about coronas and partial discharges.

b) On short circuit withstand capability, the most sophisticated technique for stress analysis and instrumentation have been applied to understand the dynamic behavior of the windings. Recurrent surge technique can now detect minor displacements in windings.

c) Development is underway to monitor the behavior on a continuous basis.

There are many other changes like these. For example, relays have been electromechanical devices for a long time but recently electronics starts to be useful in that application. Solid state relays are becoming very popular. As time goes on digital circuits and computers may take over many of the functions which are served by conventional relays at the present. This can then be combined with other functions that can be served by digital computers such as overall system control and substation automation. But these are the natural process of evolution. Suffice to say that technology will provide us with the equipment need for future transmission systems.

5. <u>Unconventional Transmission</u>

Guided microwave transmission has been suggested. In this system, the power plant generator output must be converted into radio frequency energy for transmission through a closed wave guide system and reconverted into 60 hertz AC power at the utilization terminal. Much research and development are required to determine the feasibility and economics of this transmission mode for large amounts of power. The wave guide is large and requires close aligning tolerances which may not be practical for underground systems in congested areas. Converters and couplers require basic research. It would appear that research on previously noted projects appear to be more productive at present.

The use of solar energy has been suggested. In this scheme light cells would be placed in orbit in space to absorb the sun's energy. Transmission would be by microwave from the orbiting solar energy converter to very large receiving areas in deserts. Conversion to DC would occur in these areas with DC transmission to points of utilization. Much research is needed for this scheme. There is the environmental question of dedicating to this purpose large land areas for the receiver station. There are hazards to air carriers in the vicinity of the micro-wave transmission. The tremendous expenditures required for research and prototypes, the environmental and hazard problems do not appear to justify pursuing this transmission mode while earth based fuel supplies exist for many years in the future.

Consideration has also been given to transmit energy in the form of hydrogen through pipe lines to generating plants near load centers where it would permit "clean" burning in city areas. This appears more prudent than other unconventional power transfer schemes but economic evaluation has not been finalized.

6. <u>Transmission Expansion Planning</u>

It should now be obvious that planning the transmission systems for the 1990's is a most difficult task because:

1) Equipment decisions have long term effects requiring a 15 to 25 year study period.

2) There are several alternate means of generating electric power, for example by nuclear, fossil or falling-water fuels and in large, medium or small size plants.

3) There are several alternate means of transmitting electric power, for example by alternating or direct current, overhead or underground, and at a wide range of voltages.

4) Uncertainty exists concerning the study parameters such as future fuel costs, interest rates on money, equipment forced outage rates and new technologies.

To help the planner formulate and evaluate the many and lengthy expansion alternates, a unique set of planning and simulation methods have evolved. These methods are implemented by digital computer programs and are directed by engineers trained especially for generation and transmission system planning.

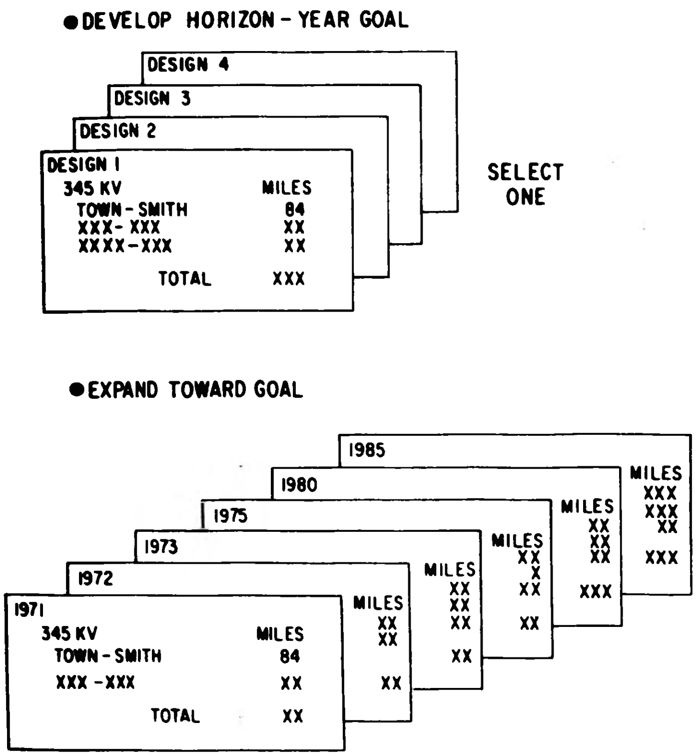

Figure 14. Two step approach to long-range transmission expansion planning

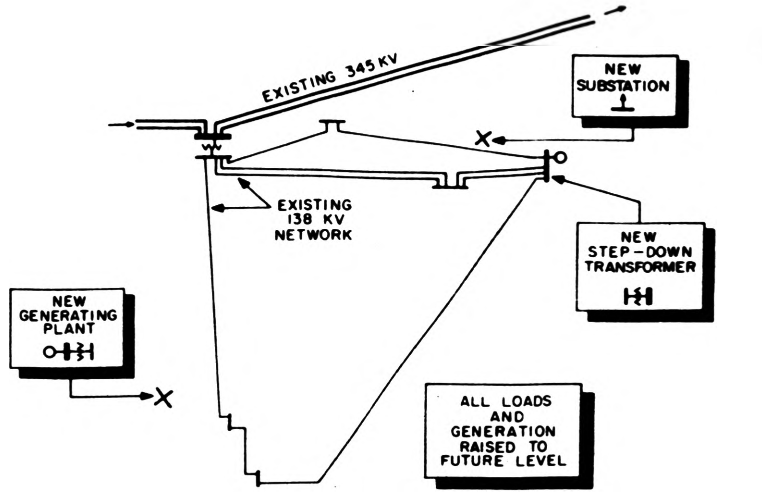

Figure 15. Initial network with future generation and load sites

Briefly, we start out with the assumption of loads for a horizon year and the permissible generation sites. For that the long term generation expansion planning is then computed using probability methods. In this program, the reliability of system reserve is evaluated. The transmission planning program lays out a sequence of transmission system additions that will be adequate from the viewpoint of system performance while achieving minimal expenditures. To achieve this objective transmission planning is done is two steps: (Figure 14)

1) A thorough study is made of the final year of the study, the horizon year, to determine the most desirable transmission system to have in place at the end of the study.

2) The original system is then expanded on a year-by-year basis adding transmission as required but at all times making sure that the additions specified are consistent with the horizon year plans.

The input data required by the Transmission Estimation Program is illustrated in Figure 15. Horizon-year designs are based on the following assumptions:

1) The existing network will be used as a starting point.

2) The location and magnitude of all future loads and generation are known.

3) The permissible voltage levels are specified.

The results from the Transmission Estimation Program include:

1) Summary of all input cases.

2) Circuit additions for each voltage class planned including the terminal points, the length in miles and whether this circuit was formed by looping an existing circuit into a bus, whether it was the second circuit on an existing tower line, or whether it represents a completely new construction.

3) The cause of the circuit addition, i.e., a generation-load schedule or a line outage test.

4) The total miles of circuits for each voltage class planned.

5) Power flow estimated for all generation-load cases and line outages with the circuit additions in place.

6) A list of possible alternate circuit additions, ranked in order of their estimated ability to improve the network.

The Transmission Estimation Program is thus able to present to the system planner information that will give him a good picture of his future network if he follows the proposed plan of generator sites, transformer sites and voltage classes allowed.

Once the system planner has determined the horizon-year design that appears best suited to his company the Transmission Estimation Program is used to proceed through time and determine the installation dates for new circuits. The network additions are now biased toward those circuits appearing in the horizon design. However, circuits not appearing in the horizon are allowed as needed. Experience in several pool studies has shown that different circuits will be necessary. Is a horizon study that important if different circuits will appear? Plans developed without a horizon guide have been compared to those using the horizon guide and the plans biased by the horizon design have always proven more economic.

A SYSTEMS APPROACH TO THE DESIGN OF A HYDROGEN ECONOMY

Joel Hebert

Department of Mechanical and Aerospace Engineering and Materials Science
Rice University
Houston, Texas

ABSTRACT

A description of the organization and methods used to select and direct participants in the design of a hydrogen energy system; a hydrogen economy. The Systems Design concept was used throughout the task, including inputs from applied psychology. Task and time organization was such that the eighteen participants completed the task, including report writing, in eleven weeks (8000 man hours).

Projected costs of producing hydrogen from coal or from nuclear heat are in the range of $1.00 to $1.50 per million Btu. Transmission and distribution costs are estimated to be about half as much. Possibilities for large scale usage of hydrogen were explored, and recommendations were made.

INTRODUCTION

Through man's history he has moved from one energy "age" to another with relative ease. We have progressed from a widespread use of wood and farm wastes in the middle ages, to coal during the industrial revolution and beyond, to petroleum and natural gas today. In each instance we have changed from one "infinite" energy source to another primarily because of economics. It became cheaper to mine coal than to chop wood at the rates one wished to use it, for example.

The current energy problems present a different picture. In the not too distant future we will change from oil and natural gas to other sources of energy. But we will not make the change to an infinite source; at least not in the sense that a very large amount of cheap energy will become available. Rather, we will begin to tap those sources which become economically competitive as oil and gas become increasingly scarce and increasingly expensive. In the near future the United States will undoubtedly use more coal, a fuel which had been priced out of some segments of the marketplace in the recent past.

This phenomenon and others which have been brought to light by the energy shortage have caused engineers and scientists to reassess their ideas about energy systems. In particular, they are realizing that there is a lack of methodology to analyze and synthesize energy systems.

This paper concerns the design of a hydrogen energy system - a hydrogen economy. However, the basic concepts and methods used could apply to the design of any large scale change in the economic system. The Systems Design approach was used as a design philosophy and procedure. The design was carried out in the summer of 1973, at the NASA Johnson Space Center. It was one of a series of annual Systems Design Institutes sponsored by NASA, the American Society for Engineering Education (ASEE), and various universities. The universities involved in this one were the University of Houston and Rice University.

Why Hydrogen?

Petroleum and natural gas serve as both energy supplies and energy carriers. The only other widespread energy carrier in use today is electricity. As petroleum and natural gas supplies are depleted this country will undoubtedly turn increasingly to coal for its energy supply. Coal, however, is a relatively inefficient energy carrier. That is to say, it is hard to transport it from place to place. It would be more efficient to convert the coal to an easily transportable form of energy, then transport the energy for ultimate use. This is done today by those electric utility companies which use coal.

Other alternatives are to convert the coal to a liquid or gaseous form. One such form is hydrogen. There would be distinct long term advantages to choosing hydrogen; chief among them being that as coal resources are depleted, nuclear energy could be used to produce hydrogen from water. The economy could then make a transition from coal to nuclear energy as a supply of energy, without altering the transmission, distribution, and usage systems. In the longer time frame hydrogen could be produced from solar energy, again without altering systems downstream from the source.

DESCRIPTION OF DESIGN PROCESS

Advance Work

Work was initiated in October, 1972 with a proposal from the Power and Propulsion Division of NASA-JSC to design a hydrogen energy system. It was felt by NASA management that the topic would be timely, and that NASA would be a valuable source of information about hydrogen in general.

Following concurrence by the Institute directors, information was sent out through the normal channels open to ASEE. This was begun in December, 1972. Every member of ASEE receives such announcements, as do department chairmen and deans of engineering.

In March of 1973 a meeting was held at which most of the Institute Fellows were chosen. Six people formed a selection committee; one from NASA-JSC, two from the University of Houston, two from Texas A & M University, and one from Rice University. Judgments were made on the basis of written applications from each of the prospective Fellows. Each application was marked by each committee member with a 1, 2, or 3; 1 being the highest rank. Thus each applicant had a summed score from 6 to 18. In general, selection was made on the basis of these summed scores. Eighteen participants were finally chosen for the program. A list of participants and their diciplines can be found in the Appendix.

During the months of January through May, 1973 the directors organized the program and made arrangements for the Fellows' ancillary needs. This included such things as provision of working space, provision of literature search capability, provision of computer facilities, and information on housing. A seminar and short course program was also arranged. The aim of this activity was to make it possible for the Fellows to begin the design task with a minimum of preliminary work.

Orientation and Team Building

Approximately three days were spent on orientation. The first day was devoted to organizational sessions and a tour of the Johnson Space Center. During the second day the participants created a preliminary organizational structure, and by the third day had replied to the work statement. Such things as library orientation were also done by the third day.

The fourth and fifth days were spent in an activity which has been called team building[1]. Using an intensive series of lectures, tests, and role-playing "games", a professional counselor presented a philosophy of group interaction which has been found to be productive. The model used was the managerial grid model developed by Blake and Mouton[2]. The individual testing was administered with commercially available tests developed by Hall and Williams[3]. The results of the tests show where the testee stands relative to the managerial grid model, and the counselor recommends steps to move from this standing to the "ideal" position. For this activity to be effective it is imperative that it be conducted by a well trained counselor. Peter Diehl, staff consultant at Miami Dade Community College, was chosen for this team building session.

It is impossible to measure the effect of the team building sessions objectively. It was felt by both the Fellows and the directors, however, that it was an invaluable aid to group decision making.

Task Completion

Work on the task progressed as shown on the time-task chart of Figure 1. A detailed time-task flow diagram can be found in Reference (4). In Figure 1 Work Program Objectives refers to the creation of an organization structure and a reply to the original work statement. This was completed during the first week. The final organizational structure of the design team, with personnel assignments, is included in the Appendix. Also included in the Appendix is a list of the directors.

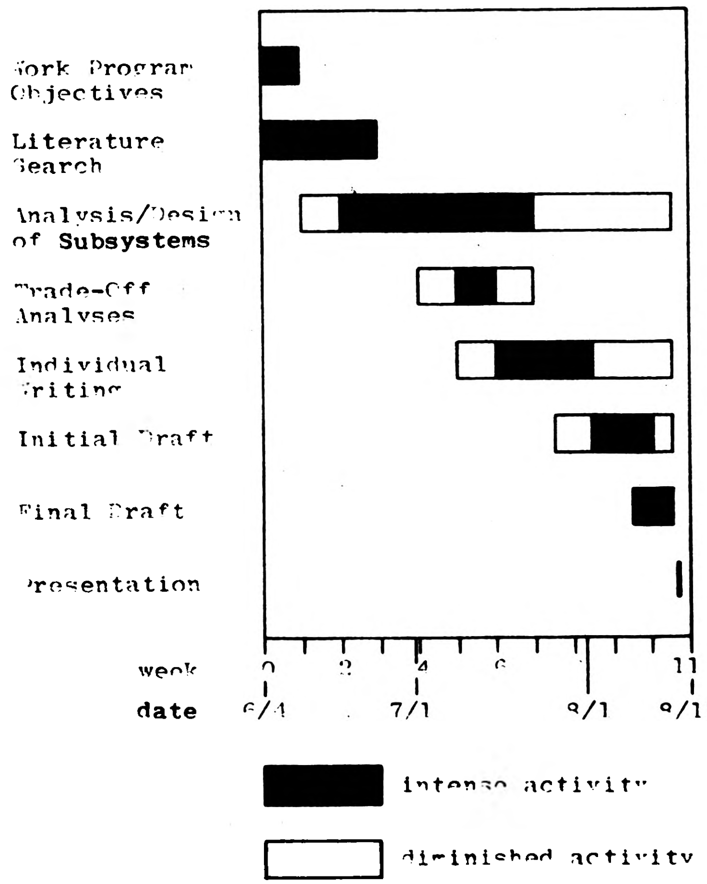

Fig. 1. Time-task chart.

The Systems Design approach[5,6,7] was used throughout the task. In actual design the first task of each group was to find and categorize all systems and subsystems pertinent for group study. The production group, for example, produced the schematic diagram shown in Figure 2. In this figure energy sources are shown at the left, processes are located in the middle, and the product, hydrogen, is indicated at lower right. Each path from a source to hydrogen is a possible production method. Similar schematics were produced by the other groups.

In order to choose between the many alternatives available, a formal trade-off analysis was done for each system or subsystem within a group. A matrix including

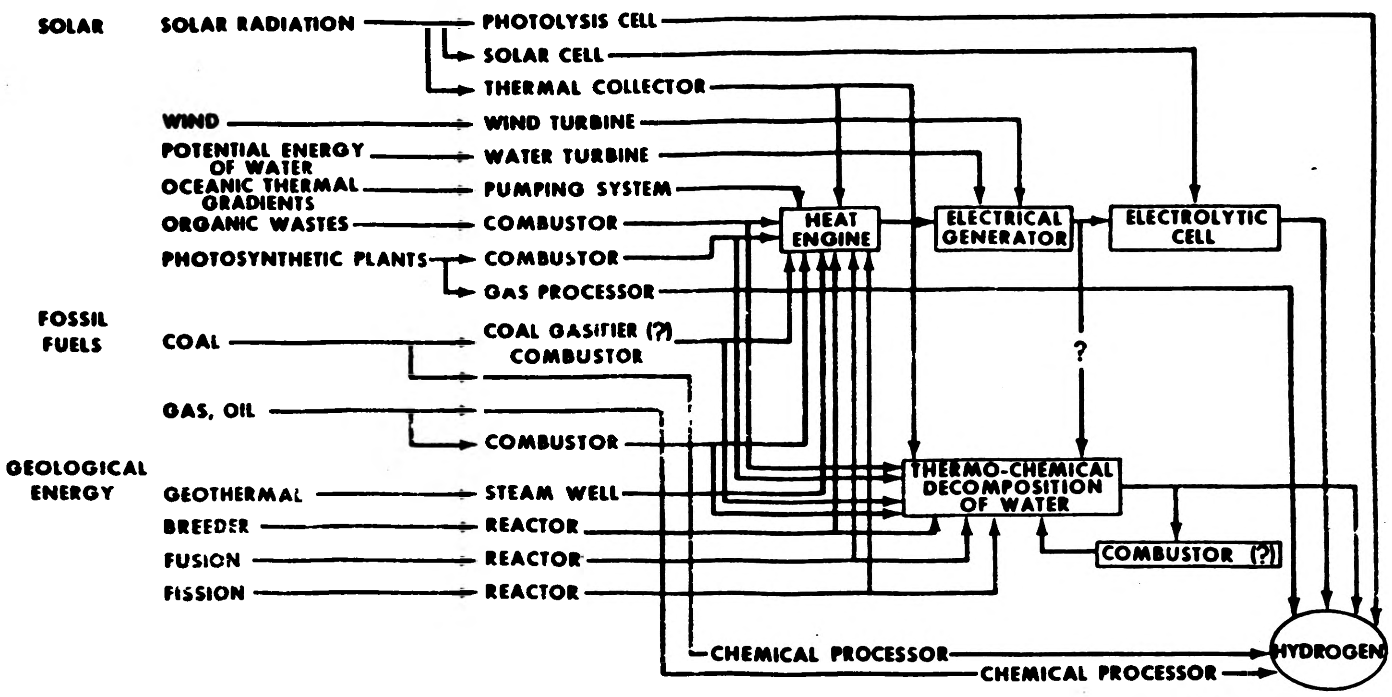

Fig. 2. Summary of methods for hydrogen production. From Reference (4).

24 factors, both technical and nontechnical, was developed for this purpose. Ratings were assigned on a scale from 1 (most favorable) to 5 (least favorable). For example, the use of hydrogen in catalytic burners for home heating might rate a "1" with respect to air pollution, but a "5" with respect to needed technology. Where known, dollar costs were used as rating figures. Each system was also rated for four specific time periods: (1) 1973-1975, (2) 1975-1985, (3) 1985-2000, and (4) 2000-2020.

Within each group this procedure aided system selection. Then the selections were matched between groups to ensure compatability. This method was found to be an effective way to aid decision making in a problem of this complexity. A detailed account of the trade-off study and the matrix can be found in Reference (4).

RESULTS

The results of the study are given in great detail in Reference (4), and in summary form in Reference (8). The most important of them will be presented here, in group format.

Production Group

The Production Group generated Figure 2 as described, then proceeded to subject all paths in Figure 2 to trade-off analyses. The results are indicated in Figure 3. This figure shows cost projections for the five most promising system alternatives for producing hydrogen, covering the 50 year time span from 1970 to 2020. All projected costs are within an order of magnitude. Thus it is unlikely that one process would completely dominate the hydrogen market, except that coal gasification and nuclear heat-thermal decomposition would be clear choices for the near future. It is expected that these two processes could produce gaseous hydrogen in the range of $1.00 to $1.50 per million Btu.

Transmission and Storage Group

All economically competitive methods of production will yield hydrogen in a gaseous form. Transmission and storage considerations have thus focused on the gaseous state. A hydrogen gas pipeline system seems to be the most practical solution. In addition it would be possible to use depleted natural gas fields and aquifers for large scale underground storage. Small scale but more costly storage could be furnished by high pressure gas tanks, cryogenic liquid tanks, and mined caverns.

It would be most advantageous and economical to use the existing natural gas pipeline system, which consists of over 900,000 miles of pipe. The possibility of this is uncertain at present, however. When certain metals are plastically deformed in the presence of hydrogen gas, cracking can occur at the metal surface. This is known as hydrogen environment embrittlement. This is a new phenomenon, and relatively little research has been done on it, in particular no research relative to hydrogen environment embrittlement has been done on in-service natural gas pipeline steels.

The factors which seem to influence hydrogen environment embrittlement in steels are the susceptibility of the steel, the stress level of the steel, and the purity of the hydrogen. An impurity of 200 parts per

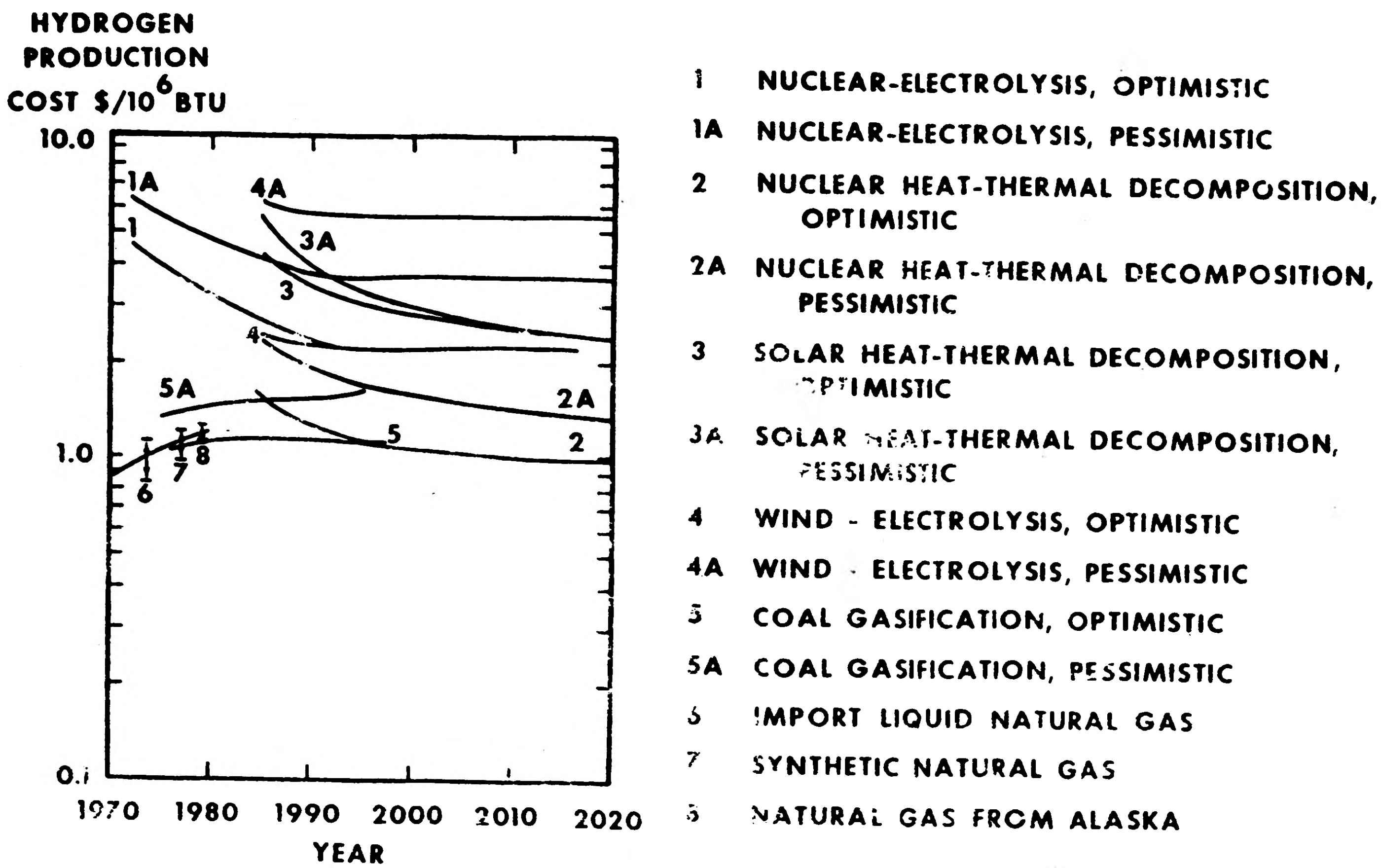

Fig. 3. Hydrogen production cost for various path alternatives. From Reference (4).

million of oxygen, for example, can inhibit this type of embrittlement[4].

Given the characteristics of the present natural gas pipeline system and proposed hydrogen production methods, the use of the present system seems favored. Before this course is taken, however, much research must be done in order to answer the questions about hydrogen environment embrittlement.

The economics of gaseous pipeline transmission per se are quite favorable. The use of existing natural gas pipelines would require four times the present compressor capacity and five times the present compressor power, to deliver energy at the same rate. Hydrogen gas transmission would thus cost about double natural gas transmission costs. These costs would still be significantly less, however, than overhead electrical transmission costs. In general, transmission and distribution costs for hydrogen would be approximately half as much as production cost.

Usage Group

The usage group was able to identify five areas into which total United States energy usage could be divided. These are residential and commercial, industrial fuel, transportation, electric power generation, and industrial chemical. The term "electric power generation" refers to the net energy consumed by the electric power industry, and is normally equated with energy rejected in the form of heat.

In assessing which usage areas could or should convert to hydrogen the emphasis was on optimum use of all fuels, as opposed to maximum use of hydrogen. Thus, for example, even though hydrogen fueled internal combustion engines work very well, it was decided that hydrogen should not be used as a transportation fuel because of its poor volume energy density.

Table 1 summarizes the pertinent conclusions relative to usage area. The transportation area is the only one for which conversion to hydrogen is advised against. Even here hydrogen might find a small direct rule and a large indirect role to play. Although liquid hydrogen has a low volume energy density (0.31 that of gasoline), it has a high mass energy density (2.58 that of gasoline). Thus fuel mass limited transportation systems could use liquid hydrogen to advantage. Commercial and military aviation both fit this category.

The indirect role concerns the use of hydrogen to produce synthetic fuels. Hydrogen can be combined with nitrogen to produce ammonia, and it can be combined with coal to form synthetic gasoline and lubricating oils. In addition, the usage of hydrogen in other

Table 1. Summary of Usage Group results.

Usage Area	Feasible Systems	Impact Evaluation	Estimated Convertability to Hydrogen
Residential and Commercial (23% of total energy use in 1970)	Converted vented combustors Unvented H_2-air combustor Catalytic burner Absorption refrigeration system Fuel cell	Unfavorable-Cost of changeover; System upgrading to ensure safety Favorable-Ecologically desirable	About 85%; that percentage presently used for purposes other than lighting
Industrial Fuel (30% of total energy use in 1970)	Conversion of existing furnaces Aphodid burner-Rankine cycle H_2-air furnace designed specifically for H_2 IC engine Gas turbine	Unfavorable-Cost of changeover Favorable-Reduction of air pollution	100%
Transportation (24% of total energy use in 1970)	Many systems operate well on H_2, but low volume energy density limits range considerably	Increased availability of fossil fuels as H_2 is used in other areas	Nil, except for possibilities in commercial and military aviation
Electric Power Generation (17% of total energy use in 1970)	Conversion of existing furnaces Aphodid burner-Rankine cycle H_2-air furnace designed specifically for H_2 IC engine Gas turbine	Aphodid burner or H_2-air furnace would be of considerably smaller size than present furnaces Improved air quality	100%
Industrial Chemical (6% of total energy use in 1970)	Hydrogenation of coal for gasoline and lubricating oils Ammonia manufacture Hydrogenation of natural oils Hydrogenation of benzene to hexane, for nylon Reduction of iron ore Methyl Alcohol	Release of fossil fuels for use in other areas	About 50%; that percentage presently using H_2 from hydrocarbons

areas would free existing hydrocarbons for use in transportation.

Figure 4 shows the forecast for convertability to hydrogen from 1970 to 2020. In this figure "Total Conservation Demand" refers to the result of a study done by two participants[9]. It is a projection of U.S. energy demand, assuming strict but realistic conservation measures for the years indicated. The portion not convertible to hydrogen reflects the judgment that hydrogen would make a poor fuel for transportation purposes.

SLEEPS (Safety, Legal, Environmental, Economic, Political, and Social) Group

The SLEEPS group was composed of a Political Scientist, an attorney, and one representative from each of the other three groups. They did not generate designs or recommendations *per se*. Rather, their task was to gauge analyses and designs relative to the six coordinates comprising their title. As such, their effort is diffused throughout the resultant design. The chief instrument for accomplishing this diffusion was the trade-off study done for each system. The primary responsibility for writing and administering it was given to this group.

Safety aspects were investigated primarily by this group. This was a high priority item, since hydrogen has a popular reputation as an extremely dangerous substance. Compared to natural gas its safety deficits are that it is much more prone to leak, its ignition energy is much lower, and it is flammable over a much wider range of fuel-air mixtures. In addition, it burns

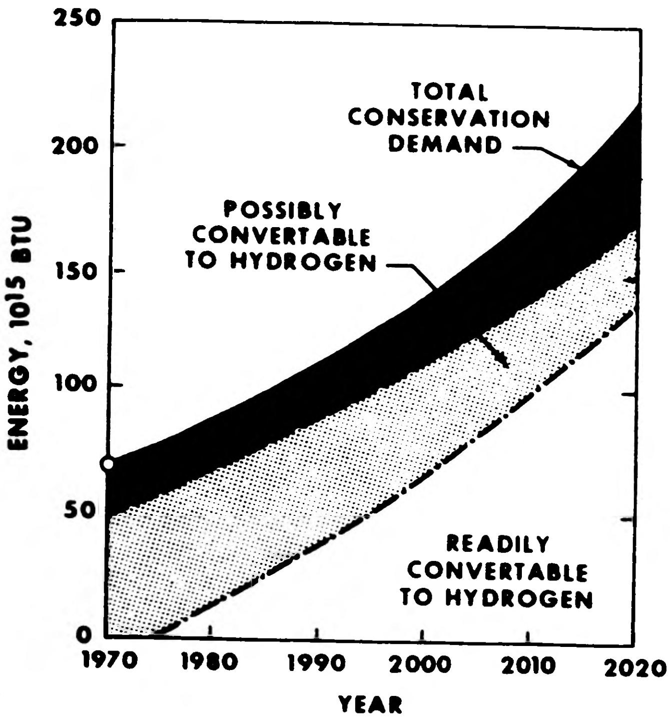

Fig. 4. Forecast of hydrogen convertability, 1970-2020. From Reference (4).

with an almost invisible flame.

On the positive side, its diffusion rate is much higher. Thus it will leave the scene of a leak much faster, diminishing the time and volume in which a flammable mixture occurs. The nearly invisible flame means that radiant heat is much less in hydrogen fires. This helps diminish injury, and offers less resistance to fire fighting and salvage efforts.

On balance, hydrogen is no more or less inherently unsafe than fuels in common use. Thus the usage areas of industrial fuel, electric power generation, and industrial chemical, all of which consider safety precautions a normal part of their operations, should be able to accept hydrogen in stride. The residential and commercial sector is less safety conscious in general. Here special efforts should be taken to make designs tamper-proof and to upgrade systems to make them less susceptible to leakage. This will represent an investment cost of large magnitude, and thus it is cited as an unfavorable impact in Table 1.

The two non-engineers in this group performed another vital function. Since they had no preconceived ideas about the hydrogen economy, nor about engineering concepts and practices in general, they were able to see others' efforts from a different perspective. Using techniques taught in the team building sessions they were able to share their observations with the engineers. It is felt that this, and the reciprocal interaction, contributed substantially to overall design excellence.

DISCUSSION

This has been a description of a process, the process being the design of a major new energy system. Although the particular result is a hydrogen economy, the concepts and methods used could be applied to the design of any large scale new system which must fit into the United States socio-economic pattern. Uniqueness was present only in the particular disciplines of the participating Fellows.

The methods of systems design and cost-benefit analysis used by this team are by no means the only methods available. There are several highly developed techniques for technology assessment[10,11] and complex decision making[12] which should be employed in any such task in the future.

It is not possible to gauge objectively the worth of this design effort. However, some observations of a subjective nature can be made. The Institute has two objectives: education of the participants in Systems Design techniques, and performance of a design task. To meet both objectives, participant selection is intentionally slanted toward those with limited experience. This forces them to simultaneously acquire experience and generate results. The final report is evidence that this was done successfully.

The time allotted was nominally 8000 man-hours. This is 200 man-weeks, or about a five month effort for a 10 man engineering-social science team. This would be a fairly small scale project for either industry or government. If one assumes that ten times the effort should be expended to yield a working system design, one realizes that reasonably sized crash efforts might yield some solutions to United States energy problems in the near future.

APPENDIX

Program Directorate

Co-Directors
- Dr. [illegible]. J. Huang, University of Houston
- Ms. B. [illegible]. Landi, NASA-JSC

Associate Director
- Dr. J. R. Howell, University of Houston

Technical Director
- Dr. W. R. Downs, NASA-JSC

Assistant Director
- Dr. [illegible]. J. Hebert, Rice University

Design Team

Team Leader
- Dr. Robert Savage, Chemical Engineer

Production Group
- Dr. Kenneth Cox, Leader, Chemical Engineer
- Dr. Saul Chao, Chemical Engineer
- Dr. Melvin Eisenstadt, Mechanical Engineer
- Dr. Stamatis Paleocrassas, Nuclear Engineer
- Dr. Richard Williams, Chemical Engineer
- Dr. Jeffrey Witwer, Mechanical Engineer

Transmission and Storage Group

Dr. Harold Koelling, Leader, Materials Engineer
Dr. Samuel Lee, Mechanical Engineer
Dr. Leonard Traina, Civil Engineer
Dr. Albert Wilson, Nuclear Engineer

Usage Group

Dr. Richard Murray, Leader, Mechanical Engineer
Dr. Leland Blank, Industrial Engineer
Dr. Richard Johnson, Mechanical Engineer
Prof. Samuel Powers, Mechanical Engineer
Dr. Richard Riley, Mechanical Engineer

SLEEPS Group

Prof. Thomas Cady, Leader, Attorney
Dr. Jack Salmon, Political Scientist
Dr. Leland Blank
Dr. Albert Wilson
Dr. Jeffrey Witwer

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DEVELOPMENT OF THE SOLID WASTE RESOURCE

David L. Klumb
Project Manager

Earl M. Wells
Engineer

Union Electric Company
St. Louis, Missouri

ABSTRACT

This paper describes the waste processing and boiler feed facilities which serve as the prototype for Union Electric Company's proposed Solid Waste Utilization System for recycling essentially all the solid waste generated in the metropolitan St. Louis area. The recently announced system, capable of proce-sing up to 8,000 tons of raw refuse per day and estimated to cost $70 million, will be built and operated without government subsidy. Solid waste will be processed for the recovery of recyclible non-combustibles and use as a supplementary fuel to electric utility boilers.

INTRODUCTION

Since April of 1972 the City of St. Louis, Missouri and Union Electric Company have participated in a test program to determine the suitability of burning processed household refuse in an electric utility boiler.

The project designers planned to test the hypothesis that domestic solid waste, milled inexpensively to a small particle size, could serve as a supplementary fuel for firing in a utility boiler. Further, by replacing only a small percentage of the total fuel fired, there would be little difference in effect on the boiler than if 100 percent coal were burned.

The solid waste processing facility, which is located adjacent to the South one of the two City incinerators, has been jointly financed by the City of St. Louis and the U. S. Environmental Projection Agency. The processed refuse storage and boiler firing facilities located at the Meramec Plant, which is some 20 miles from the processing facility, have been completely financed by Union Electric Company.

During the first year of operation the prototype performed satisfactorily with the exception of the milled solid waste mechanical handling systems. Throughout this period only magnetic metals were separated from the milled refuse prior to firing to the boiler. Crushed glass or other solid nonmagnetic particles were an occasional cause of jamming in the feed mechanism supplying the material to the pneumatic transport system. The quantity of noncombustibles removed with the boiler bottom ash was excessive and finally abrasive wear was evident at the pneumatic transport piping bends and elbows. These problems were identified soon after the initial operation.

Late in 1973 a mechanical air separator (air classifier) was added to the processing plant following the milling operation. The air classifier in operation since mid-November 1973, has alleviated the equipment jamming and bottom ash problems.

The prototype has demonstrated that the designer's basic hypotheses were valid. To date the material has presented no insuperable operating problems at the processing plant or in the utility boiler. The processed solid waste, with a heat value of around 5,000 Btu/lb, has been a suitable supplementary boiler fuel.

PROCESSING FACILITIES

The City of St. Louis is responsible for processing the solid waste and transporting the conbustible fraction to the Meramec Plant. The City facility is designed to process the raw refuse at the rate of 45 tons per hour or 300 tons for an 8-hour shift. The one shift operation of the City plant will supply supplementary fuel for replacement of 10% of the coal requirement of the Meramec boiler for 24 hours.

The hammermill is a horizontal shaft mill powered by a direct-connected 1,250 hp, 900 r/min. motor. The mill grate has openings of 2¼ inches by 3¼ inches, but most milled particles are less than 1½ inches in size. The milled material will vary greatly in density depending on moisture and the degree of compaction, from a low of 4 lbs/ft^3 to a high of 12 lbs/ft^3.

Figure 1 provides a schematic flow diagram of the City processing facility.

The milled refuse is conveyed to the air classifier metering and surge bin which provides a controlled feed into the entrance of the air classifier. A cross section of the classifier is shown in Figure 2. The light burnable components of the milled refuse are carried with the air flow and discharged through the top of the classifier, while the heavy particles fall out the bottom onto a conveyor belt. The heavies are conveyed under a magnetic belt separator for removal of magnetic metals. A 100 hp vertical "nuggetizing" mill increases the density of the magnetics to about 65 lbs/ft^3. The dense nuggetized metal passes over a magnetic drum for separation of any remaning nonmagnetic metal.

The magnetic metal is transported to the Granite City Steel Company for use as scrap for charging blast furnaces.

The heavy fraction remaining after removal of the magnetics is currently being taken to landfill. However, plans are underway to provide for separation of the glass, organics, and nonferrous metals into separate components.

The light fraction from the classifier is carried by air to a cyclone separator and discharged to a conveyor belt to the storage bin. Loading the storage bin from the top and withdrawing from the bottom provides for first in, first out scheduling. The material withdrawn from the bin is compacted into conventional 75 yd^3, self-unloading transfer trailer trucks and transported approximately 20 miles to the Meramec Plant.

RECEIVING AND FIRING FACILITIES AT MERAMEC

Union Electric Company is responsible for the operation of the system starting with the surge bin at the Meramec Plant. Figure 3 is a diagram of the facilities at the power plant. The combustible portion of the solid waste is discharged from the trucks into a live bottom receiving bin, and pneumatically conveyed to the surge bin. The surge bin is equipped with four sweep bucket trains and four drag chain unloading conveyors which are built into troughs in the bin floor.

The material is carried into four hoppers and fed through rotary air locks into the four pneumatic feeders. Each feeder conveys the supplementary fuel through a separate pipeline to a firing port in each corner of the boiler furnace. These four pipelines are each about 700 feet long. Air velocities are approximately 85 ft/s and the particle velocities, depending upon their mass, are approximately 50 to 70 ft/s. Initial pipeline pressures normally range from 1 to 3 psig.

Figure 4 is an illustration of the type boiler used for the refuse burning. The two converted boilers were built by Combustion Engineering, Inc. Each unit is tangentially-fired, with four pulverized coal burners in each corner, and burns about 56.5 tons/h of bituminous coal at a nominal rated load of 125 MW. The furnace is about 28 feet by 38 feet in cross section, with a total inside height of about 100 feet. At full load, the quantity of refuse burned, equivalent in heating value to 10 percent of the coal, is about 12.5 tons/h, or 300 tons/24-hour day.

The only modifications made to the furnace were the refuse burning ports installed in each corner, between the two middle tangential coal burners. The solid waste is burned in suspension with the same flame pattern as coal or gas. The nonburnable particles and the particles too large to be fully consumed within the time they are exposed in the furnace fall to the bottom ash hopper and are dumped with the bottom ash.

With the prepared refuse firing at a constant rate, combustion controls on the boiler automatically vary the rate of firing the pulverized coal in order to maintain the heat requirements of the boiler. If for any reason the boiler trips suddenly, an electrical interlock immediately stops the feeding of refuse.

It appears that firing rates equal to 10-20 percent of the total heat input to the boiler are practical with the classified-milled solid waste. Since the installation of the classifier about 8,000 tons of processed refuse have been burned. Altogether since April 1972 about 24,000 tons of supplementary fuel have been delivered to the Meramec plant and fired. There is no evidence of short-term corrosion of furnace fire-side or convection section gas-side surfaces. Long-term corrosion studies are still underway and should be complete by October 1974.

ENVIRONMENTAL EFFECTS

Comprehensive environmental testing by Union Electric and the USEPA is now underway. To date there are no indications of excessively adverse effects on the environment.

Analyses of the milled, classified solid waste are shown in Table I. The solid waste samples were taken prior to loading into the transport truck. The analyses include 182 samples taken from November 1973 to April 1974. Analysis techniques conformed insofar as possible to standard American Society for Testing Materials procedures for analyzing coal and coal ash.

While the solid waste is low in sulfur and visual observation of the stack has shown no dramatic increase in the particle emissions, it must be recognized that the ash content of the classified refuse is higher than that of many coals and therefore incrementally increased dust loadings are probable.

Extensive analysis of water from the refuse ash pond influent and effluent as compared to water from a typical bottom ash pond shows no significant problems.

The emission standards for refuse burning utility boilers have not yet been established. It is hoped that the regulatory authorities will recognize that, while there may be an increase in point source emissions, a substantial net reduction in area pollution will result.

SOLID WASTE UTILIZATION SYSTEM

On February 28, 1974, Union Electric Company announced plans for the development of a Solid Waste Utilization System capable of handling essentially all of the solid waste generated in the metropolitan St. Louis region. The system is scheduled for full scale operation by mid 1977. Figure 5 presents a schematic flow diagram of Union Electric's proposed system.

Under the plan, Union Electric will establish and operate five to seven strategically located collection-transfer centers capable of handling a total of 2.5 to 3.0 million tons of waste annually. Refuse will be received from private and public haulers at these centers and transferred to closed containers for rail shipment to processing facilities at the Company's Meramec and Labadie power plants.

Meramec Plant includes two 125 MW C.E. boilers; a 270 MW Foster Wheeler front fired pulverized coal boiler; and a 300 MW Foster Wheeler front fired pulverized coal boiler. All four units will be equipped to burn processed waste at a rate equal to 20% of the units full load heat input.

Labadie Plant includes four 600 MW C.E., tangentially fired pulverized coal fired steam-electric generating units. All four units will be equipped to burn processed waste. The two plants will provide an aggregate refuse burning capability of twice that generated in the area.

The raw waste, including household wastes, appliances, commercial wastes, demolition lumber, and selected industrial solid and liquid wastes will be received at both power plants by rail. Two stages of hammermilling will reduce the solid waste to a particle size of one inch or smaller.

Following air classification, the burnable waste fraction will be pneumatically transported to the waste firing burners in the boiler furnaces. Redundancy is designed into all stages of the process to insure availability of waste processing facilities at all times at each plant.

The heavy fraction from the process air classifiers will be separated into organic, glass, magnetic, and nonmagnetic metal fractions. The organics will be returned to the hammermills for further size reduction and to preclude the need to dispose of these materials in landfill.

Composition of the waste to be received by the system is difficult to predict. A rough estimate of the waste composition is listed below:

	Percent by Weight
Burnable	80
Glass	10
Magnetic metals	8
Nonmagnetic metals	1
Rock, gravel, etc.	1
Total	100

ECONOMICS OF THE PROPOSED SYSTEM

The economic evaluation of the proposed Solid Waste Utilization System is premised on the similar processing of refuse as is done with the prototype, but with an enlargement in scale and equipment, and generally more efficient materials handling systems.

The critical factors in the economic evaluation of the process are:

1) Federal, state, and local regulation of solid waste landfills.

2) Stack emission, fuel, and waste water discharge.

3) Cost of transport of solid waste from the point of origin through processing and to the boiler.

4) Cost of alternate, environmentally acceptable methods of solid waste utilization and disposal.

5) Dumping fees at collection centers.

6) Value of recovered materials such as magnetic and nonmagnetic metals.

7) Cost of fuel.

Capital investments, revenues, expenses, depreciation schedules and taxes must be forecast for each year. The annual net cash flows are determined. Finally, the mathematics of rate-of-return and net present value analysis is applied to the after tax annual net cash flow values. The project becomes economically attractive when the rate-of-return exceeds the cost of capital, or the project is evaluated to have a positive net present value.

Obviously, a number of estimates must be made before determination of the various cash flows. One such estimate, very critical to the analysis, is that of the regulatory requirements. For example, unrealistic emission standards, with the associated increase in capital investment, could cause the Solid Waste Utilization System to be economically unfeasible.

Consequently, the management of Union Electric has requested of the regulatory authorities that they diligently strive for definitive standards for this project. The spending of the substantial sum of money needed to achieve the Solid Waste Utilization System must await this promulgation. We are optimistic that reasonable standards will be established.

CONCLUSION

The authors do not suggest the system described in this paper to be the only practiced solution to the solid waste problem. However, the fact that a Solid Waste Utilization System can be economically attractive is certainly a landmark of progress.

The problem of refuse disposal and the attendant air and water pollution and land degradation is now superseded with the opportunity to develop the solid waste resource for society's benefit by salvaging or recycling scarce materials and conserving limited natural resources.

ACKNOWLEDGEMENTS

The Union Electric Company wishes to acknowledge the contributions and continued cooperation of the City of St. Louis and Horner and Shifrin Consulting Engineers, the U.S. Environmental Protection Agency, Granite City Steel Company, the American Iron and Steel Institute, and Reynolds Metals Co.

The following companies provided services and major pieces of equipment for the prototype and continue to cooperate in the development of this process.

For the City of St. Louis:
Hammermill--Gruendler Crusher & Pulverizer Co.; Conveyors--Continental Conveyor Co.; Vibrating conveyors--Stephens-Adamson Division, Borg Warner Corp.; Storage bin, St. Louis--Miller-Hoft Corp.; Stationary packer and transfer trucks--Heil Corp.; Pneumatic transport equipment and air classification equipment --Rader Pneumatics Inc.; Magnetic metal "Nuggetizer" --Eidal Corporation.

For Union Electric Company:
Boilers--Combustion Engineering Inc.; Storage bin--Atlas Systems Inc.; Pneumatic transport equipment--Rader Pneumatics Inc.; Refuse and refuse ash analysis--Ralston Purina-Research 900.

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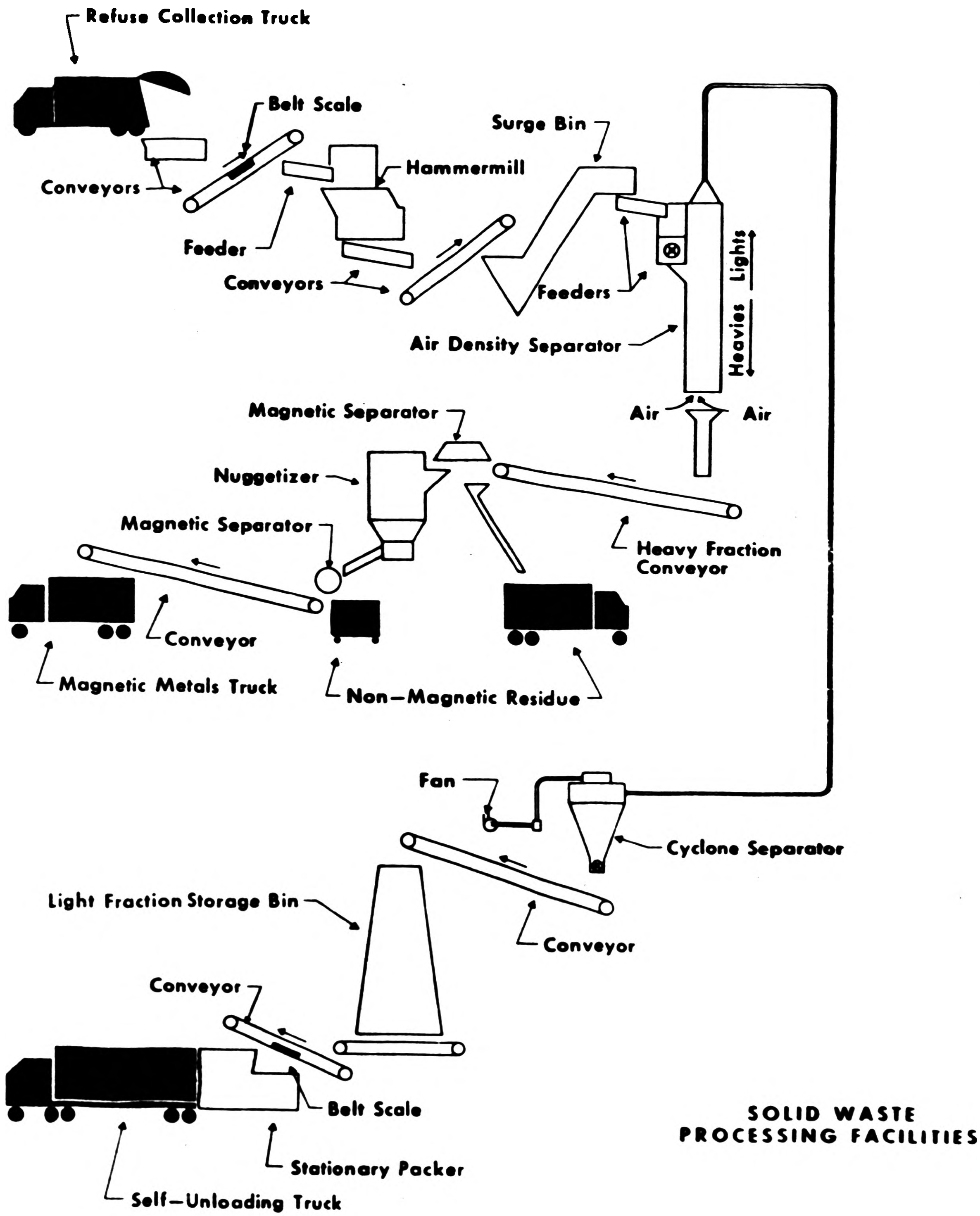


Refuse Collection Truck
Belt Scale
Conveyors
Feeder
Hammermill
Conveyors
Surge Bin
Feeders
Lights
Heavies
Air Density Separator
Air
Air
Magnetic Separator
Nuggetizer
Magnetic Separator
Heavy Fraction Conveyor
Conveyor
Magnetic Metals Truck
Non-Magnetic Residue
Fan
Cyclone Separator
Light Fraction Storage Bin
Conveyor
Conveyor
Belt Scale
Stationary Packer
Self-Unloading Truck
SOLID WASTE PROCESSING FACILITIES

Figure 1

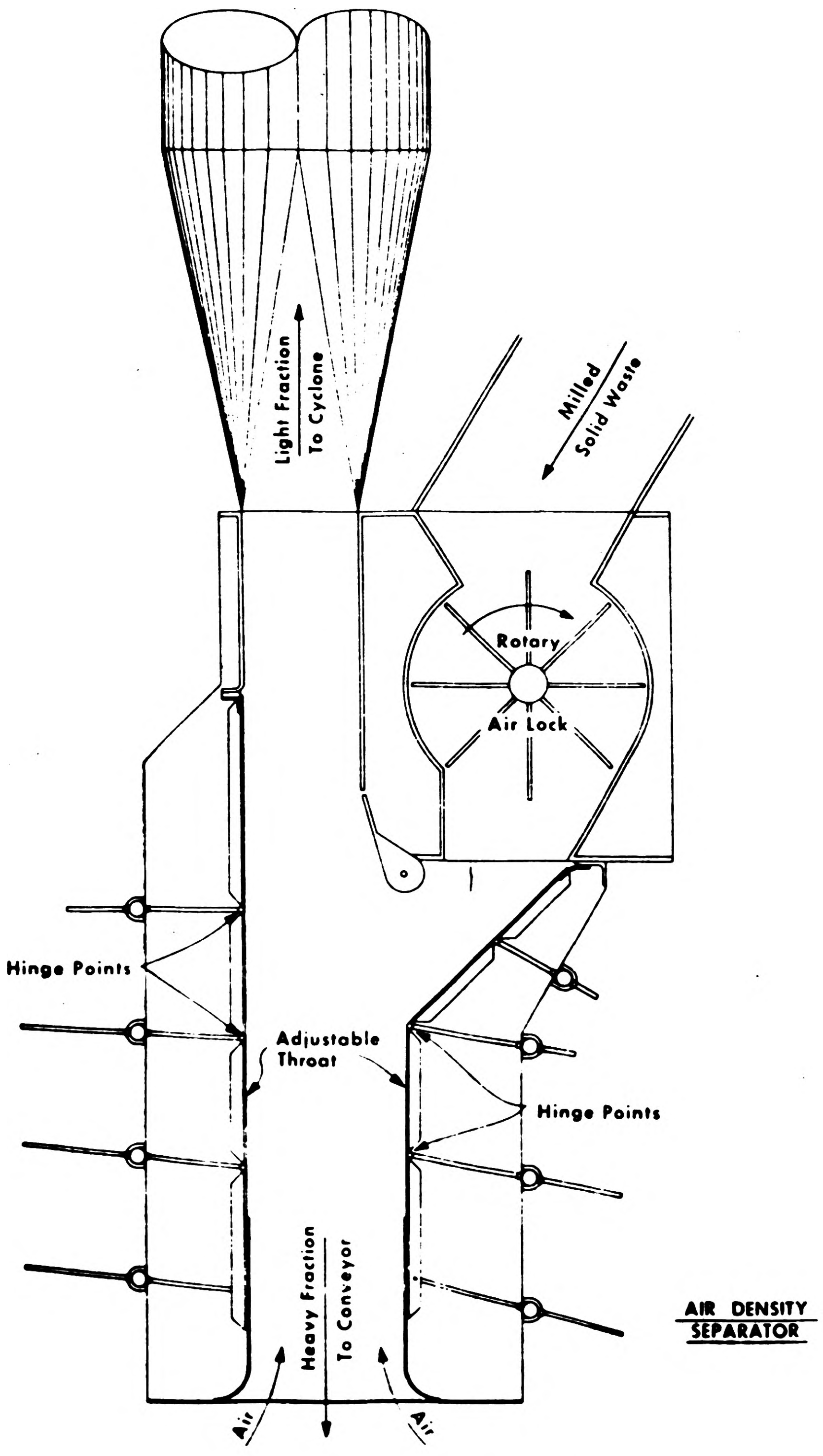

Light Fraction
To Cyclone
Milled
Solid Waste
Rotary
Air Lock
Hinge Points
Adjustable
Throat
Hinge Points
Heavy Fraction
To Conveyor
Air
Air
AIR DENSITY
SEPARATOR

Figure 2

Table I

Air Classified Refuse Analyses

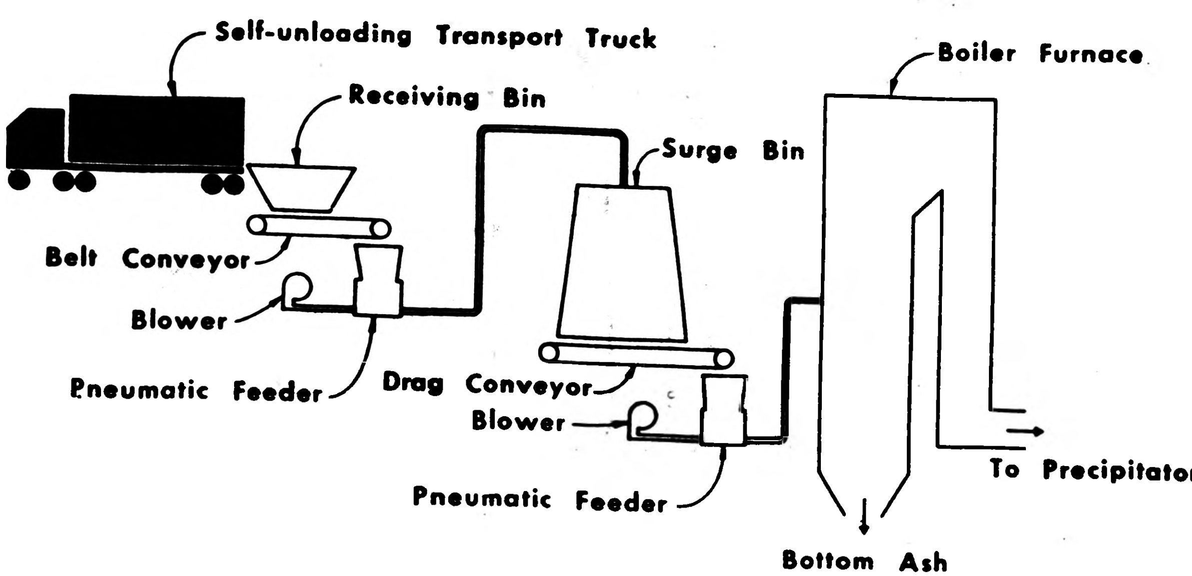
182 samples taken November 9, 1973 through April 15, 1974

As Received Basis

	Moisture (%)	Ash (%)	Sulfur (%)	Chlorides (%)	NaCl (%)	Btu/lb (%)
Average	30.5	16.8	0.10	0.41	0.32	4,959
Maximum	66.3	31.3	0.28	0.94	0.55	7,593
Minimum	11.1	7.6	0.04	0.14	0.11	2,293

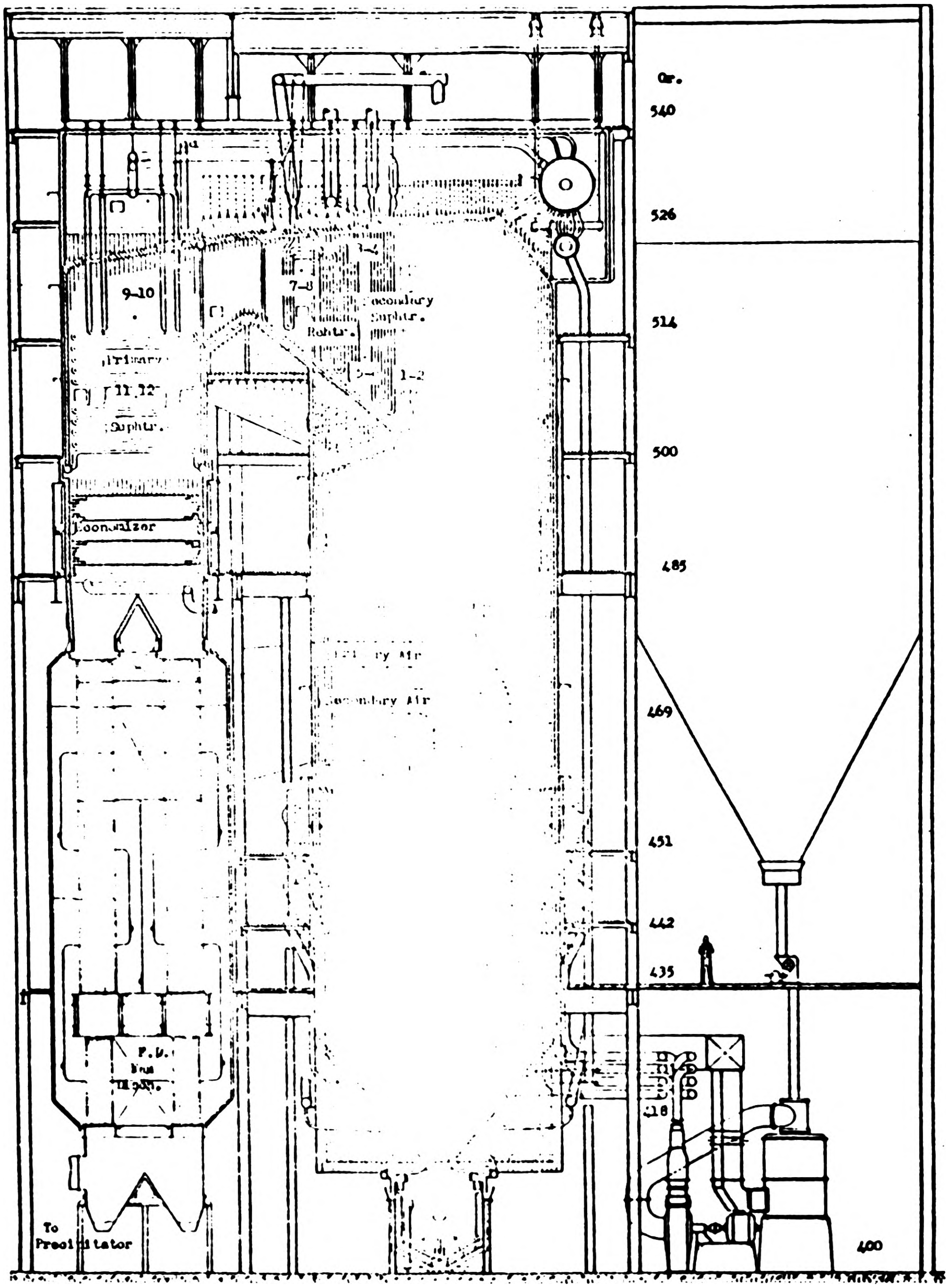
Air Classified Refuse Ash (%)

	Average	Maximum	Minimum
P_2O_5	1.44	2.04	0.99
SiO_2	49.8	56.7	39.9
Al_2O_3	11.38	26.90	6.10
TiO_2	0.88	1.52	0.07
Fe_2O_3	7.89	22.19	3.03
CaO	12.36	15.80	9.09
MgO	1.33	2.32	0.22
SO_3	1.53	3.75	0.73
K_2O	1.59	2.91	0.92
Na_2O	8.92	19.20	3.11
SnO_2	0.05	0.10	0.02
CuO	0.33	1.74	0.08
ZnO	0.42	2.25	0.09
PbO	0.20	0.73	0.04



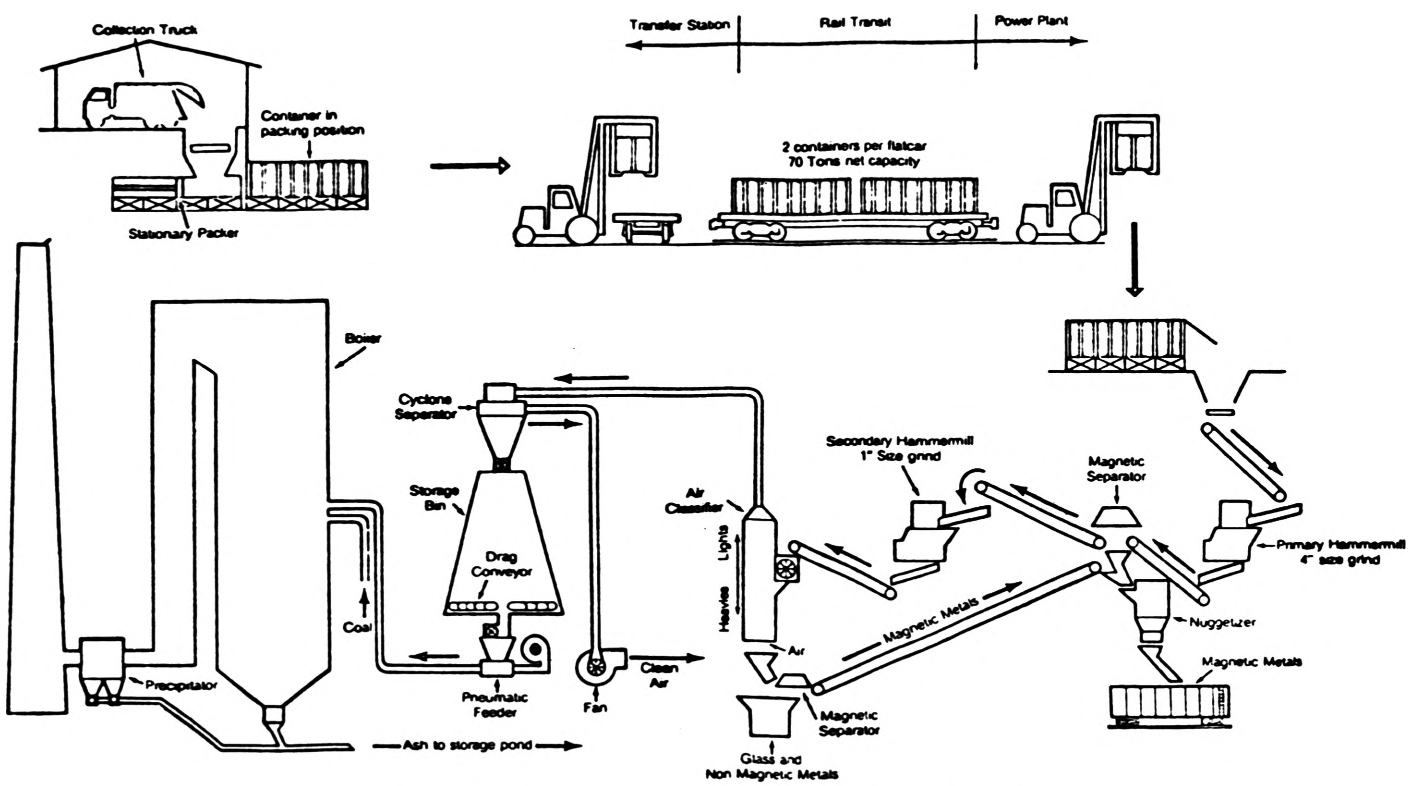
SUPPLEMENTARY FUEL RECEIVING AND FIRING FACILITIES

Figure 3



C-E REHEAT STEAM GENERATOR

MERAMEC POWER PLANT Figure .



UNION ELECTRIC CO. • SOLID WASTE UTILIZATION SYSTEM

Figure 5

A PROPOSED COAL SLURRY PIPE LINE

R. W. TOLER
Arkansas Power & Light Company
Pine Bluff, Arkansas

ABSTRACT

Investigation is underway to determine the feasibility of building a slurry pipe line over 1000 miles long to deliver coal from Wyoming to the Arkansas-Louisiana-Mississippi area. This paper describes some of the features of the project.

INTRODUCTION

Last year, Middle South Utilities* and Arkansas Power & Light Company announced plans to build a coal-fired power plant near Redfield, Arkansas, using four 700 mw generating units. Two units are to be completed in 1978, one in 1980 and one in 1981. Four additional units of like size will follow at, as yet, undisclosed sites but probably not in Arkansas. The plant near Redfield has been named White Bluff after the 90-foot high bank of the Arkansas River on which the site is located.

COAL REQUIREMENTS

White Bluff will require 10 million tons of coal per year with all four units operating at the expected load factor.

Total coal requirement for the four White Bluff units, plus the four additional MSU units, is about 20 million tons per year. Delivery will be made initially by unit trains of 100 cars, each having a capacity of 100 tons. Thus, each train hauls 10,000 tons.

Because of the gigantic proportions of present day fuel problems in general, four operating companies of Middle South Utilities have formed a subsidiary, System Fuels, Inc., which has already made coal commitments for White Bluff. They are active in securing coal for the additional four Middle South generating units.

PIPE LINE STUDIES

Preliminary studies of coal transportation for eight large generating units led to formation of Energy Transportation Systems, Inc., which is composed of System Fuels, Inc., Bechtel, Inc., and Lehman Brothers, Inc. Under study is an underground pipe line about three feet in diameter to deliver coal in slurry form from the mines near Gillette, Wyoming, via Nebraska, Kansas and Oklahoma to the MSU area. One terminal is tentatively planned for AP&L's White Bluff Plant. The preliminary route under investigation involves many crossings of railroads, rivers and highways. Capacity of the proposed pipe line is on the order of 25 million tons per year or enough coal for the eight proposed MSU generating units, plus two additional future units. The proposed pipe line would transport coal equivalent to the capacity of 45 trains making 2500 round trips per year. At this rate, a train would pass a given point on the common portion of the route every hour and 45 minutes. Diesel fuel requirements for the locomotives would be 140 million gallons per year.

*Operating companies of Middle South Utilities (MSU) are Arkansas Power & Light Company, Arkansas-Missouri Power Company, Louisiana Power & Light Company, Mississippi Power & Light Company and New Orleans Public Service Inc.

COAL SLURRY PIPE LINES NOT NEW

Coal slurry pipe lines are not new, the first one having been installed in 1914 in England from coal docks on the Thames River to a boiler plant 1750 feet away using 8" cast iron pipe with bell and spigot joints.

The first significant commercial coal slurry pipe line in the United States was designed by the well-known 80-year old New York firm of engineers and constructors, Ford, Bacon and Davis. President and Chairman of the Board of this firm was Charles C. Whittelsey, a 1925 graduate of the Missouri School of Mines, now known as the University of Missouri at Rolla. The honorary degree of Doctor of Engineering was awarded to Mr. Whittelsey in 1960 by his alma mater. Ford, Bacon and Davis designed the 108 mile long 10" pipe line for the Consolidation Coal Company to deliver coal from the mines near Cadiz, Ohio, to a 600 mw power plant at East Lake, Ohio, near Cleveland. It operated relatively trouble free from 1957 to 1963.

The 273 mile 18" Black Mesa-Mohave line began delivering coal in 1970 to a 1500 mw generating station.

There are dozens of other solids pipe lines throughout the world delivering limestone, copper ore, magnetite, gilsonite and mine tailings.

ADVANTAGES

One inherent advantage of a coal slurry pipe line is the opportunity to upgrade the coal. This operation would include separation of pyrites and washing to remove clays and some of the sulphur. Removal of the clays aids in dewatering. Pyrites are abrasive to the pipe line and are detrimental to pipe line hydraulics.

ENVIRONMENTAL CONSIDERATIONS

An environmental impact statement will be required for the coal slurry pipe line covering:

- Environmental Setting Description
- Project Description
- Environmental Impact Assessment
- Methods to Minimize Impact
- Short Term Environmental Uses versus Long Term Productivity
- Irreversible Environmental Changes
- Alternate Routes

Environmental impact statements will also be required for the surface mining operation and each power plant.

TYPICAL OPERATION

A typical mine to furnace operation would entail the following:

- Mine
- Stock pile
- Grinding
- Cleaning
- Slurry preparation

Tankage
Pumping stations (electric lines, substations)
Dewatering
Storage
Plant bunkers
Furnace
Ash disposal

Particle size of the coal as prepared for slurry is expected to be about as follows:

+ 14 mesh - nil
+ 20 mesh - 1% to 2%
+ 325 mesh - 20% to 23%

No pipe erosion of any consequence is expected. Studies of the Ohio and Black Mesa projects show no appreciable particle size degradation in transit. With proper attention to grading the pipe line, plugging can be avoided.

RIGHT OF WAY

Present plans, which are only preliminary, call for 100 foot wide right of way which is expected to be adequate for three or four pipe lines. The permits will allow for coal, oil, gas or electric lines. It is entirely possible that existing electric, gas and oil line rights of way can be shared when in the proper location and direction.

WATER

Three test water wells have been drilled in Wyoming to the Madison limestone aquifer at about the 3000 foot level. The test wells indicate an adequate water supply is available without jeopardizing supply to others. Water from these deep wells would not be suitable for agricultural use because of the high cost of pumping.

FINANCING

Financing the project will be undertaken only after completion of:

All engineering and feasibility studies completed
All rights of way acquired
All permits in hand
Firm transportation contracts.

CONCLUSION

The tremendous amount of coal required by eight large generating units makes transportation a herculean task. In the final analysis, the slurry pipe line is expected to have the advantages of economics, operating flexibility, conservation of energy and environmental superiority. It is emphasized that the project is still in the planning stage and much analysis and study remain to be done before proving the project to be feasible.

CLEAN FUEL FROM COAL

FOR ELECTRIC POWER GENERATION

J. Agosta
Commonwealth Edison Company

INTRODUCTION

Several strategies have been studied and applied for the reduction of sulfur-dioxide emissions from power generation sites. These include switching to low sulfur fuels, stack gas processing, and a greater reliance upon nuclear power. One area of interest is the processing of fuel prior to combustion through the total gasification of coal to produce a fuel gas suitable for combustion in utility boilers and gas turbines. Specifically, this paper will deal with need for coal as a fuel in the generation of electric power, the production from coal of a clean power fuel gas of approximately 150 to 200 Btu and its application to present and future coal-fueled generating units.

With an anticipated scarcity of all clean fuels, the electric utility options until recently were nuclear fuel, natural gas, low-sulfur oil, and low-sulfur coal; however, due to the recent oil embargo and regulatory actions, oil is subject to very serious supply disruptions and it has been suggested that many utilities who converted to oil convert back to coal.

Estimates of the United States natural gas supply-demand balance clearly shows the critical natural gas shortage faced by the U.S. projected deficit by 1985 of over 30% is a quantity generally agreed upon. Even if the demand for natural gas is reduced by price increases or by restrictions on end-use, it is apparent that the use of natural gas for power generation, other than peaking and ignition, is questionable.

Nuclear fuel is not presently limited by supply. Its major use is of course for the production of electric power. Shortages, that have occurred, have mainly been caused by vacillating and rapidly changing regulatory and environmental constraints. In general, nuclear units are presently competitive only for base-load generation and there is still a need for intermediate and peak load generating capacity.

Low-sulfur coal may not satisfy the future demand for low-sulfur fuels over the long term. In the short term, the mining and transportation industries will have difficulty responding adequately to a rapid shift in demand. Also, a rapid shift to low-sulfur coal may create significant economic dislocations in both of these industries with the resultant effect of making the large tonnages needed in the future more difficult to obtain.

Another indication of the seriousness of problems associated with coal is related to existing plant. A warning issued by the Federal Power Commission in a report[2] release in late February pointed to potentially critically deficient power supply reserves in seven of nine designated electric reliability areas if compliance with present 1975 air quality ordinances is mandated. Choices are limited to (a) compliance with the installation of scrubbers which are not yet proven, (b) request for a variance, or (c) shutdown. In the area of MAIN (Mid-America Interpool Network), it was reported that 13 generating plants with a capacity of 10,817 mw would not be able to comply with the standards. The effect is to reduce the estimated reserve from 17.3% to 14.4% deficit. Unless variances are granted curtailment of electric service can be predicted.

There are only two significant resources which will provide long-term solutions; they are coal and nuclear fuel.

Of course, coal is one of the largest resources of fossil fuels in the United States; however, by ordinance, most of it is environmentally unacceptable. Against the background of a scarcity of available clean fuels, most knowledgeable sources predict a need for coal and estimate an increase in coal consumption well into the next century and beyond. The bulk of the Midwest's coal reserves are high sulfur and almost off limits to the power plant market[3]. Environmental ordinances would eliminate a significant part of the coal being mined in the Midwest. If it is assumed that 3.0% maximum level of sulfur is allowable, 81% of Illinois' coal reserves and all of the coal in Missouri would not be acceptable as would be the case with much of the other Midwest states' coal reserves. If the coal industry is to be preserved, it is necessary to make high-sulfur coal acceptable as fuel, or modify environmental goals.

During 1974, it is estimated that Commonwealth Edison projected requirements are that uranium will provide fuel for 34.5%, coal 54%, oil 9% and natural gas 2.5% of the total estimated kilowatthours of production. Of the 54% from coal, 30.5% points will be Illinois coal and 23.5% points low sulfur Western coal. Estimated 1982 fuel mix is 50% nuclear, 40% coal and 10% oil. Moreover, although the percentage of coal in the total estimated fuel mix drops from 54% to 40%, the annual tonnage predicted for 1982 is considerably more than requirement. It is apparent there is a significant commitment to nuclear power generation; however, it is clear that coal will play a vital role in the fuel supply scenario.

Proposed methods of using coal and meeting environmental ordinances have centered about stack-gas clean-up systems. We are pessimistic about all sulfur-dioxide removal processes which have been developed thus far. Commonwealth Edison has installed two such processes at a cost of about $25 million. Despite continuing efforts, neither process is working satisfactorily, although more than two years have passed since their December 1971 service dates.

If it were reasonable to assume that a system installed in the near future would operate satisfactorily with the required reliability, the economics appear to be still highly unfavorable. Recently, proposals for sulfur-dioxide removal equipment, which was to be installed on a proposed new generating unit, were received from a number of manufacturers that have experience in this technology. These proposals either did not comply with specified sulfur-dioxide removal guarantees, were developmental proposals without cost guarantees, had unrealistically high power requirements, or were a combination of these items. Moreover, capital costs were considerably higher than had been anticipated. More recent experiences by other electric utilities has confirmed these facts.

CLEAN FUEL FROM COAL INVESTIGATIONS[5]

Over a period of about 5 years, Commonwealth Edison engineers* studied many clean fuel from coal processes. As a result of this intensive activity, we arrived at two fundamental conclusions: one, no clean fuel from coal technology had been developed to the point where it could be applied on the large scale and with the reliability needed for power generation purposes; two, there is a potential that clean fuel from coal processes may become economically feasible and could play an important role in electric power generation. Further, it has been concluded that only low Btu pressurized gasification has a reasonable chance of being economically produced on a commercial scale within the near term. Although fuel processing is attractive, it is the author's view that it is unrealistic to commit power systems to an immature technology on existing plants or those already planned and on order.

Significant development efforts are being directed to converting coal to pipeline quality gas and to liquid fuel. In addition, other programs are being directed to converting coal to pipeline quality gas and to liquid fuel. In addition, other programs are being directed toward the production of low Btu gas by the removal of undesirable ash and chemical constituents to provide a clean fuel. Low and intermediate Btu gas differs from natural gas in both its energy per unit volume and chemical constituents. Natural gas has approximately 1000 Btu/SCF and is about 95% methane. Depending on the production process, low Btu gas with 150-200 Btu/SCF would have about 5% methane with the remaining energy mostly in the form of hydrogen and carbon monoxide. Intermediate Btu gas would have about the same chemical constituents as low Btu gas. Oxygen is used to gasify the coal for intermediate Btu; whereas air is used for low Btu gas production. For power generation, the processes involved may utilize commercial equipment adapted to the task, but assembled and operated in a new and unique fashion. Thus, there is significant risk involved in developing low Btu gas through the pilot and demonstration plant stages.

When comparing processes for the production of low Btu gas versus pipeline quality gas, it is found that low Btu gas production process is much simpler since there are no oxygen, methanation, and CO_2 shift conversion facilities required. For these simpler processes, lower capital requirements, a lower operating cost and higher energy recovery efficiency are predicted. Moreover, direct integration with a power plant will permit recovery of sensible heat and an 80 percent or more overall efficiency for a low Btu gasification process is expected.

Studies indicate that the use of low Btu gas in a new conventional coal-fired station may be competitive with stack-gas scrubbing.

Although the cost of retrofitting is viewed as being considerably higher than for a new plant, the use of low Btu gas may not only be environmentally superior to stack-gas scrubbing, it also has the potential of being equal to, or less costly than, retrofitting stack-gas clean-up systems. Detailed studies of specific backfit installations are required for a determination of the most economical system. These studies would include items such as the age and remaining life of the existing plant, space requirements, and boiler derating (capacity loss) due to the lower heating value of the gas. For some cases, an intermediate Btu gas may be appropriate as a retrofit to boilers design for natural gas. Generalization of cost estimates for retrofit entail a risk of large inaccuracies.

A previous publication[6] pointed to the combined-cycle plant (with low Btu gas production) as promising environmental superiority, higher efficiency, lower cost and further improvement in the utilization of coal. This is contrasted with the "dead-end" technology of stack-gas clean-up systems which misuse resources and which may never meet the reliability and environmental ordinances required of power generation. When one compares the two technologies it is found that low Btu gas technology leads to many new options for improved power generation. Looking toward the future, it is believed that nothing on the horizon that can be done at the back-end (cleaning products of combustion) that can compete with the potential benefits that could result from combined cycle systems. The future of low Btu gasification in power generation lies in the development and use of improvements. To make these options available, the successful development of a low Btu gas production system is needed.

GENERAL PROCESS DESCRIPTION

The fuel processing scheme determines the resulting fuel gas properties and thus, overall plant efficiency levels. For the major development project which we call the Powerton Project: Clean Power Fuel Test Facility a pressurized gasification process was chosen which uses water scrubbing to remove particulate matter, a chemical was (hot potassium carbonate) process for removal of sulfur compounds, and a Claus kiln for reduction to elemental sulfur.

Six major functions of this coal gasification system are used as a basis for comparison[7]:

1. Gasification - wherin proportioned amounts of coal and high-pressure steam and air react to form gas.
2. Scrubbing - wherein the produced gas' undesirable constituents are removed by a washing process.
3. Purification - wherein hydrogen sulphide (H_2S) is removed.
4. Sulfur reduction - wherein elemental sulfur is produced from H_2S.
5. Gas heating - wherein the gas is heated to a temperature such that the fuel gas conditions - following expansion in the expander turbine will be suitable for power plant combustion.
6. Expansion compression - wherein a gas expansion turbine drives an air compressor providing air for the gasification section.

COMPARATIVE ECONOMICS

Detailed economic analyses comparing a new conventional plant with stack-gas scrubbing against a plant with low Btu pressurized coal gasification have been made with the processes integrated into the steam-generating plant. Costs for the low Btu gasification process were based on present technology.

For new integrated plants, the expected capital cost of a large scale gasification process is about $85 to 90 per kw. This was compared with a stack-gas scrubbing process at $100 per kw. In addition, when using gasification, equipment elsewhere in the power plant will be eliminated resulting in cost reductions. These reductions result from savings in the boiler and associated equipment (as compared to a coal-fired unit) and from an increase in the capacity of the plant due to a difference in auxiliary power. Reductions are estimated to range up to $45 per kw. The total capital cost differential could be as much as $45 per kw in favor of gasification.

The overall plant efficiency could be from 15 percent to 20 percent greater for some stack-gas scrubbing processes. This presumes that stack-gas clean-up can be made to operate satisfactorily. Some of the most recently proposed "dry type" stack-gas clean up systems may have requirements for a clean fuel input (as a reducing agent) that could result in significantly lower efficiencies.

The results of these studies show that the total cost of power from a fossil-fired steam-generating plant could be lower with low Btu gas as compared to using high sulfur coal and stack-gas scrubbing. This conclusion needs confirmation by actual experience, however, studies by others have arrived at the same conclusions.[8]

The most significant economic advantage of low Btu gasification has been considered.[6] Upgrading coal through pressure gasification allows coal to be used for power-production cycles presently restricted to premium fuels. This opens the door to potentially greater capital savings and higher efficiencies of the combined steam and gas turbine cycle.

POWERTON PROJECT: CLEAN POWER FUEL TEST FACILITY

Commonwealth Edison jointly with the Electric Power Research Institute is sponsoring a major research and development project leading toward the production of a clean fuel from coal for electric power generation in the shortest practical time and thus clarify the economics and environmental impact of future large scale plants.

Construction should begin late in 1974 on the proposed Powerton Project: Clean Power Fuel Test Facility. This project is designed around Lurgi technology. There is a sense of urgency to develop technology to use high-sulfur coal.

This project should bring together power generation and chemical processing industry technology. The engineer, chemical or power oriented, must learn to respond to operational requirements required by power systems. In addition to welding these two technologies, we will proceed to investigate the problems of reacting coal at a rate which is several orders of magnitude slower than practiced in the power industry while working within economic constraints differing from the chemical industry.

One major goal of this Test Facility is to provide engineers and management with data regarding costs, safety, flexibility, and controlability and possibly proceed to demonstrate the combined-cycle plant. The first step is to build a Clean Power Fuel Test Facility which will provide fuel for existing boilers. (See Figure)

Goals of this test facility are:

. . . demonstrate that various agglomerating and non-agglomerating coals can be successfully gasified (at least 6 U. S. coals will be tested),

. . .demonstrate that substantially all the particulates can be removed from the gas,

. . .demonstrate desulfurization of the (remove about 90 percent of the sulfur),

. . .show that the production of oxides of nitrogen upon combustion are reduced,

. . .demonstrate that low Btu gas can be reliably burned in present and future boilers,

. . .demonstrate that the various systems will perform in concert probably for the production of power,

. . .demonstrate that such a system can be substantially automated to minimize manpower requirements,

. . .demonstrate that these systems operating in concert can be responsive to system load,

. . .demonstrate that gas quality can be maintained,

. . .provide economic and design data for large conventional and combined cycle plants.

ENVIRONMENTAL ASPECTS

The production of a low Btu clean gas from high-sulfur coal should result in significant reductions of contaminants to the environment. The degree of reduction will be dependent on the gasification and the desulfurization processes selected.

Reductions of about 90 percent in sulfur dioxide, virtually 100 percent in particulates, and significant reductions of nitrogen oxides are expected. Ash should present no unusual disposal problems, such as those presently encountered with wet flue gas SO_2 removal processes. Water treatment processes are generally available for the small quantities of contaminants generated in the coal gasification particulate scrubber.

A NEED

There have been many discussions which have centered on the relative advantages of various gasification, liquifaction and clean-up technologies. This paper has not attempted to argue the merits of today's state of the art technology versus that yet to be developed. There is need for clean power fuel from coal today and in the future. Although the starting point described is the fixed-bed pressurized gasifier, it does not preclude the development of fluidized-bed, entrained-bed, molten-bath, underground gasification, and liquifaction which all may contribute unique advantages to producing electricity and mitigate energy resource problems for utilities and the nation. A recent report from the National Academy of Engineering said: "The need of industry and utilities for a clean fuel is so great that it is decidedly in the national interest to develop as quickly as possible the lowest cost reliable gasification process."

That is what the Clean Power Fuel Test Facility is all about. It is designed to prove or disprove the technical capability of coal gasification and gas purification to produce a clean power fuel to supply electric power generation in the shortest practicable time.

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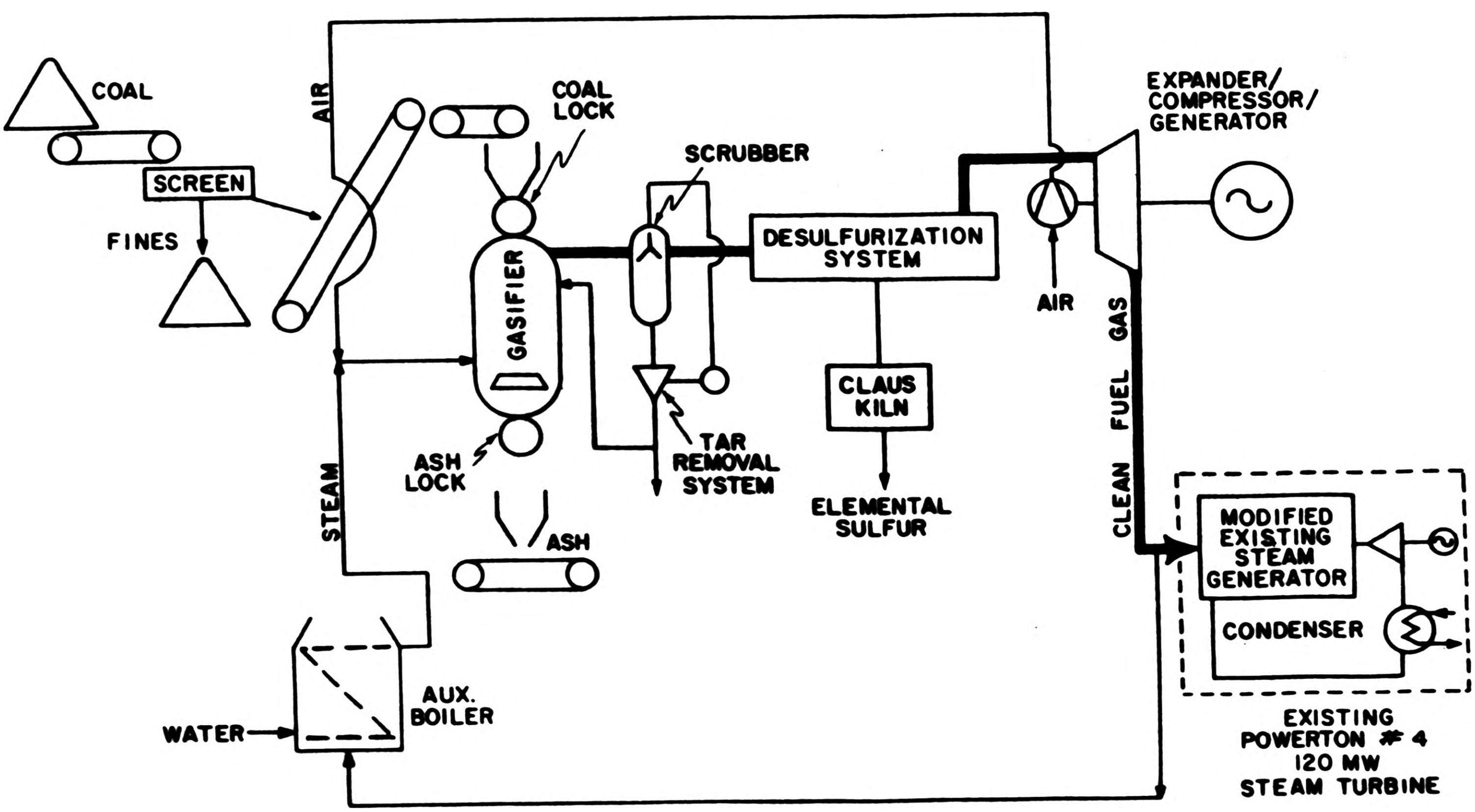


THE ASSOCIATED ELECTRIC COOPERATIVE ENERGY CONTROL SYSTEM

Douglas W. Arlig

Associated Electric Coop., Inc.
Springfield, Mo.

ABSTRACT

Associated Electric Coop. installed a digital computer energy control system in 1971 to improve the economics and security of its power system operation. Since its initial implementation, the new energy control system has been undergoing a continuing evolutionary process. The addition of new data acquisition systems, improved man-machine interfaces, and the development of new, more sophisticated application programs has helped bring the system closer to its goal of reliable, secure, and economic power system operation.

This paper describes Associated's energy control system as it was originally installed, as it is currently operating today, and as it is currently envisioned to operate in the future. Emphasis is placed on the evolutionary nature of the automation of power system operations in light of the growth of the power system, its increased complexity, and the ever advancing technology of power system computer applications.

INTRODUCTION

Associated Electric Cooperative, Inc. is an electric cooperative corporation organized under the laws of the state of Missouri, with headquarters in Springfield, Missouri. It comprises the following electric generation and transmission (G&T) cooperative members which operate in the states of Missouri, Iowa, Kansas, Nebraska, and Oklahoma.

Central Electric Power Cooperative
Jefferson City, Missouri

M&A Electric Power Cooperative
Poplar Bluff, Missouri

Northeast Missouri Electric Power Cooperative
Palmyra, Missouri

N.W. Electric Power Cooperative, Inc.
Cameron, Missouri

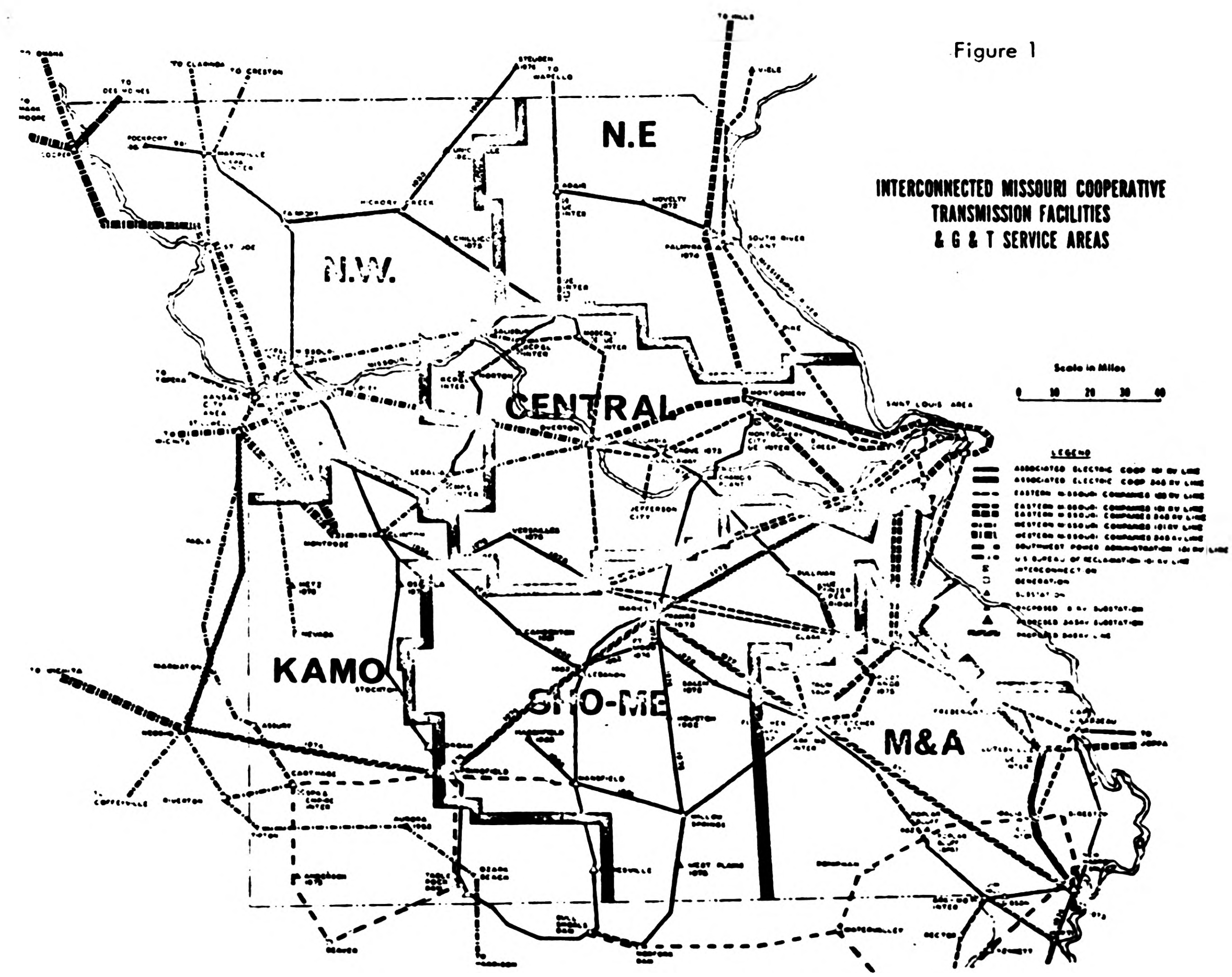


Figure 1

Sho-Me Power Corporation
Mansfield, Missouri

KAMO Electric Cooperative, Inc.
Vinita, Oklahoma

Associated was formed for the purpose of supplying its members with electrical power and energy at the lowest practical cost by utilization of the power sources and transmission lines available to it. Associated is, with minor exceptions, the sole supplier of the power requirements of its members. The member G&T's are, in general, the sole power suppliers of 43 member distribution cooperatives in Missouri and Iowa. These members distribute electricity to approximately 320,000 customers in the state of Missouri.

The Associated system peak load for 1973 was 910,000 kW, and electric energy sales for 1973 were over 4,150,000,000 kWh. The total present generating capacity is 1,225,000 kW with 600,000 kW of additional generation under construction for completion in 1977.

The bulk transmission facilities (Figure 1) of the system are composed of some 1422 miles of 345, 161, and 138 kV lines, which are used primarily for the transmission of power to the Distribution Cooperatives' 69 kV distribution systems. This power is transmitted through some 35 161-69 kV, 161-138 kV, and 345-161 kV substations having an installed transformer capacity of approximately 2967 MVA.

Associated is interconnected with some 14 operating utilities in the states of Missouri, Iowa, Kansas, Oklahoma, and Arkansas at 44 tie points.

The operation of the power system is coordinated from Associated's system Control Center which is located at its headquarters in Springfield, Missouri. Communications between the control center and the power plants, points of interconnection with other utilities, metering points necessary for system control is via a private microwave system.

Power System Operations

The primary goal in the operation of an electric power system is to supply the power required to meet customer demands in an economical manner consistent with system security. In order to achieve this goal, power system operations personnel are required to perform continuous and comprehensive analyses to evaluate the current system performance and to ascertain the effectiveness of alternative plans of operation. These analyses can be classified as operations planning, operations monitoring and control, and operations accounting and review.

The problems of operations planning involve calculations required to reach decisions concerning the next hour, day, week, or month of system operation. These analyses include the following: 1. Load Forecasting 2. Maintenance Scheduling 3. Spinning Reserve Determination 4. Unit Commitment Scheduling 5. Interconnection Transactions Evaluations.

Operations monitoring and control are involved with those problems requiring instant-by-instant determination on a real-time basis. These tasks include: 1. Monitoring and Alarming 2. Economic Allocation of Generation 3. Load and Frequency Control 4. Voltage and/or var Scheduling 5. Remote Supervision of Transmission Facilities.

Operations accounting and review analyses involve after-the-fact evaluations such as: 1. Interconnection billing 2. Energy Accounting 3. System and Unit Production Statistics 4. Post Disturbance Review Analysis

In each of these areas of power system operations the key considerations are economy and security of system operation. Because of the size and complexity of today's large, interconnected power systems, analog and/or digital computer systems are required to perform many of these operating functions in order to insure reliable and economic power system operations.

The paper that follows describes the automation of Associated's power system operations. The evolution of Associated's energy control system is traced from the installation of an on-line digital computer control system in 1971 to its current status. Future plans for energy control system improvements are also discussed to ascent the continuing process of automation.

AEC ENERGY CONTROL SYSTEM

In 1971, Associated installed a new digital dispatch computer system to improve the monitoring and control of its power system operations. An important constraint on the design of the new digital control system was that it be compatible with the existing control equipment. This constraint was improtant both from economic and reliability standpoints, since it both minimized the amount of new hardware required and allowed the existing control equipment to perform the backup function for the new system.

Existing Control Equipment (prior to 1971)

The existing equipment consisted of an analog telemetering system, chart recorders, an analog load frequency controller, a kWh digital telemetering system, and a kWh digital log unit. The operation and function of this existing equipment was as follows:

1) Analog Telemetering System - Power flows (MW) at all tie points (interconnections) and generator power outputs (MW) for all major generating stations are continuously transmitted into the control center over the microwave system where they are converted to analog values (mV).

2) Chart Recorders - All the telemetered MW values as well as system frequency, net interchange, scheduled interchange, area control error, system load, and total generation values are continuously trended on recorders.

3) Analog Load Frequency Controller - The telemetered tie flows and generator outputs are fed into the Analog Load Frequency Controller where the system control error and unit control errors (required adjustments to unit generations) are continuously calculated. Raise or lower commands are transmitted to the generating stations to effect the required changes in generation to minimize the system control error.

4) kWh Digital Telemetering System - At each tie point the interchange of energy (MWh) is metered, and at the end of every hour is transmitted into a digital receiver at the control center.

5) kWh Digital Log Unit - Once an hour, after all the metered energy values have been received, the kWh digital log is printed for use in energy accounting.

New Digital Computer System

The new digital computer system was a General Electric GE-PAC 4020 process control computer. It consisted of a central processing unit (CPU) with 24 k words (24 bits) of core memory, 131 k words of magnetic drum memory, 1024 k words of magnetic moveable-head disk memory, as well as process I/O subsystems, standard data processing peripherals, and CRT display subsystems. The process I/O equipment included both high speed analog and digital I/O subsystems and related equipment for interfacing with the existing control equipment. The standard data processing peripherals included a 300 CPM card reader, a 100 CPM card punch, a 300 LPM line printer, and I/O typer, and two output-only typers.

The new system also included two CRT display subsystems. Each CRT subsystem has two 14-inch black and white display terminals (a total of four for the system). Each terminal has the capability of displaying any of the 64 alphanumeric (A/N) characters in any position of a 22 row--46 column matrix. An electronic A/N keyboard was provided for data entry on only one of these terminals. These CRT subsystems were interfaced to the computer system via two half-duplex, bit-serial communication links -- the subsystem with the keyboard using a 4800 baud synchronous communications unit and the other a 1200 baud asynchronous communications unit.

To coordinate and control the operation of the GE-PAC 4020 computer system hardware described above, a Real-Time Multiprogramming Operating System (RTMOS) was also included. RTMOS is a grouping of programs and subroutines which supervises the inter-action of process events, time, actions by peripherals, and the CPU. RTMOS takes care of details such as responses to interrupts, scheduling of functional programs, allocation of core resources, input/output code conversions, input/output mechanics, monitoring of peripheral device status, substitution of peripheral devices, transferring of programs and data, as well as many other functions.

In addition to the standard GE-PAC RTMOS software, a background processing package, FREETIME IV, was also provided. FREETIME IV is a non-real-time batch processing function which provides for the compilation and assembly of FORTRAN IV and Process Assembly Language (PAL) programs and for program testing and debugging, and program and data table library maintenance. FREETIME IV operates while the computer system is on-line by making use of the frequent, relatively short intervals, when the computer system is not involved in active process monitoring and control. The card reader, card punch, and line printer peripherals are used primarily by this function.

Power System Operations Functions Performed

The following is a brief discussion of the salient features performed by the new digital dispatch computer system. Because of space limitations, the descriptions are brief and supporting functions are not described.

Data Acquisition -- One of the most basic and most important functions performed by the digital computer system is the acquisition of system information. This system information is of two types -- data and status. Data consists of the MW values, which are continuously telemetered into the control center from tie points and generating stations, and the frequency error, miscellaneous generation, and miscellaneous interchange values, which are derived from the analog control system. The status information indicates the condition of each of the telemetered data values. The status of the analog telemetering for each data value can be either in service, out of service, or in failure. Data values are input into the system through the analog to digital (A/D) converter while the status is a digital input. System information is acquired and updated in the system data base on $2\frac{1}{2}$ second intervals.

System Monitoring -- The system monitoring function is also performed every $2\frac{1}{2}$ seconds. It consists of the checking of the current system status for any abnormal conditions which should be alarmed. These checks include the failure of analog telemetering for extended periods of time, the input of unreasonable data values, tie line limit violations (excessive power flows), generator operating limit violations, and various system operating limit violations, such as excessive area control error.

Man-Machine Interface -- The operator's interface to the new digital dispatch computer system includes CRT display equipment, log typers, and chart recorders. The operator's console, through which the operation of the system is controlled consists of two CRT's and an A/N keyboard which has 45 function keys in addition to the standard A/N keys and entry marker (cursor) positioning keys. Through the keyboard, the operator can demand displays of various system status and parameters on either CRT as well as perform entries of various operating parameters. One CRT is used for entries and displays, the other is used for system alarms and displays. Displays of system status are periodically updated to insure the integrity of the data displayed.

In addition to the two CRT terminals used for the operator's console, there are two CRT's which are used for management information displays. Any one of four preselected displays can be called up for display through a four-button panel located with each CRT.

Two IBM Selectric 15 CPS typers are also part of the operator's interface. One typer is used for printing alarms and recording operator entries, the other typer is used for the printing of CRT displays and logs, either on demand and/or at periodic intervals.

The chart recorders are used to trend important calculated system variables. They include area control error, net interchange, scheduled net interchange, net generation, and system load. These recorders can be driven by either the analog or the digital control systems.

Automatic Generation Control -- Automatic generation control (AGS) consists of the system area control error (ACE) calculation, economic dispatch calculation (EDC), and load frequency control (LFC) functions. Since AGC is the primary operation performed by the new digital system, it will be explained in more detail.

Every $2\frac{1}{2}$ seconds, after the data acquisition function has been completed, the ACE calculation is performed. This involves calculating the actual net interchange, the deviation from the mutually prearranged (or scheduled) net interchange, and the area control error itself. ACE is the sum of the net interchange deviation and the frequency error derived from the analog system. The ACE function also calculates the net system generation, system load, and other miscellaneous values.

The EDC function periodically determines the most economical operating points for generating units required to meet the current system load. The EDC function operates in two modes -- "system dispatch" mode and "control dispatch" mode. System dispatch calculations are performed every ten minutes, or whenever system load or generation changes significantly, and upon operator demand. The system EDC is performed in the conventional manner, using individual incremental heat rate curves for each generator and penalty factors derived from a system transmission loss computation using the standard "B" matrix approach. Both manually and automatically controlled units are dispatched.

Control dispatch calculations are performed every five seconds using fixed penalty factors representing the current system state as calculated by the last system dispatch. Only automatically controlled units are dispatched since manual units are not expected to change generation over the short intervals.

The LFC function is performed every 2½ seconds to control unit generations to meet system load and reduce the area control error. The LFC function operates in two modes -- normal and assist. The normal mode of LFC operation is when the area control error is within the normal deadbaud range (+25 MW, - 25 MW) -- when economic operation is desired. The area control error calculated by the ACE function is first distributed between all units on automatic control using control participation factors. These values are then added to the units' control dispatch generation basepoints to determine the new desired unit generations. The desired unit generations are checked against the economic operating limits and if violated, are set equal to the limit exceeded. The desired unit generations are next compared with the actual unit generations to determine unit control errors. The LFC function then determines the raise or lower (R/L) control outputs that are required to reduce the unit control errors for each unit based on each units' response rates. The R/L control outputs are then transmitted to the generating units to perform the required control action.

The LFC function switches from normal to assist mode when the area control error becomes excessive and remains in the assist mode until the area control error is recuded to within an acceptable tollerance (+5 MW, -5 MW). During the assist mode of operation economics are ignored, and all units are moved to reduce area control error within the constraints of the LFC operating limits and response rates.

Interchange Scheduling -- The interchange scheduling function enters and maintains records of mutually prearranged energy transactions with other interconnected utilities and periodically calculates the net scheduled interchange for the monitoring and control functions. The function allows the entry of up to 40 separate interchange schedules for any hour and a total of up to 320 schedules for a period beginning one day in the past and running up to a year in the future. Each schedule entry consists of the following information: 1) Interchange Company 2) Type of Interchange (firm, economy, etc.) 3) Starting and Ending Time and Date of Interchange 4) Amount (MW) and direction (purchase or sale) of Interchange.

Interchange studies — Two interchange study functions are included to assist the operators in costing of energy transactions -- hourly interchange negotiations (HIN) and hourly cost reconstruction (HCR). The HIN function is used to superimpose a one hour schedule on the system for a future hour to determine the cost of the proposed transaction. The HCR function is used to compute the cost of interchange transactions for the past hour.

Energy Accounting -- The energy accounting function collects MWh data for all ties and generators in the system, updates the system energy data base, and prints hourly energy summary logs. Energy data is collected in two ways -- from the kWh digital telemetering receivers through a special digital I/O interface and by integrating the analog telemetered MW values on periodic intervals. The results are compared and large discrepancies are alarmed. The hourly energy log is printed on the log typer at the end of each hour. It contains both the metered and integrated values for ties, the integrated values for generators, and a system energy summary. This information can also be displayed and edited through the CRT console.

Post Disturbance Review -- The post disturbance review (PDR) function provides a record of system data which may be studied following a system disturbance. Data is collected continuously and maintained in revolving files such that at any point in time, when a disturbance might occur, there will be a record showing the data readings prior to the disturbance. All MW values for generators and ties are stored at ten second intervals and maintained for five minutes. When a PDR is demanded, the last five minutes of data is dumped on the line printer (optionally on cards). After five minutes of additional data is collected, a second dump occurs. This provides ten minutes of data for review - five before and five after a disturbance.

Contingency Evalutaion -- The purpose of the contingency evaluation (CEP) function is to compute the effects of a set of contingencies on a unique set of transmission lines in the system. A quantity, called a contingency distribution factor, is defined as the change in power flowing in a given line for a one per-unit change of power in some designated line or generator. These quantities are used to predict the power that would flow in each line if a designated line or generator were lost. The resulting line power flows are checked against line loading limits, and if a violation occurs, an alarm is output. The CEP function is performed periodically whenever an EDC (system dispatch) occurs.

Dispatcher's Load Flow -- A 127-bus dispatcher's load flow program is also included. It runs as a FREETIME IV program with card reader and I/O typer input and line printer output. Up to ten study cases can be stored in the disk files.

ENERGY CONTROL SYSTEM IMPROVEMENTS

Since its initial installation in 1971, the new digital dispatch computer system has been undergoing constant change. The addition of new data acquisition systems, improved man-machine interfaces, and the development of new, more sophisticated application programs have helped bring the system closer to its goal of more reliable, secure, and economic power system operation. The following section contains brief descriptions of some of these changes. The current system hardware configuration is shown in Figure 2.

Supervisory Control and Data Acquisition

In 1972, a GE-TAC supervisory control and data acquisition system (SCADA) was added to the existing ECS. It consisted of a GE-TAC Remote Station which was installed at a new 161/345 kV substation located at the site of the new 600 MW City of New Madrid generating plant and a GE-TAC Supervisory Communications Coupler on the GE-PAC 4020 computer system as well as new supervisory data acquisition and control software functions. Through the SCADA system, the system operators are now able to remotely monitor and control the operation of one of the most critical substations in the system (600 kV transmission line, 161/345 transformer rated at 350 MVA, and 345 kV transmission line).

Improved Man-Machine Interfaces

Three major improvements have been made with respect to the dispatcher's CRT console. First, a second duplicate CRT console has been installed to improve the reliability of and the accessibility to the primary operator's interface with the computer system.

Second, CRT display and entry formats and procedures have been modified or changed extensively to improve the efficiency and effectiveness of the dispatcher's consoles. Additional displays have also been added for the SCADA system.

Third, a small push-button panel has been added to the dispatcher's console to supplement for several lengthy CRT console procedures, which are performed at frequent intervals, and to display the raise and lower control outputs which are transmitted to the generating units. Through a simple one-button procedure, the operator can put a generating unit on control or take it off.

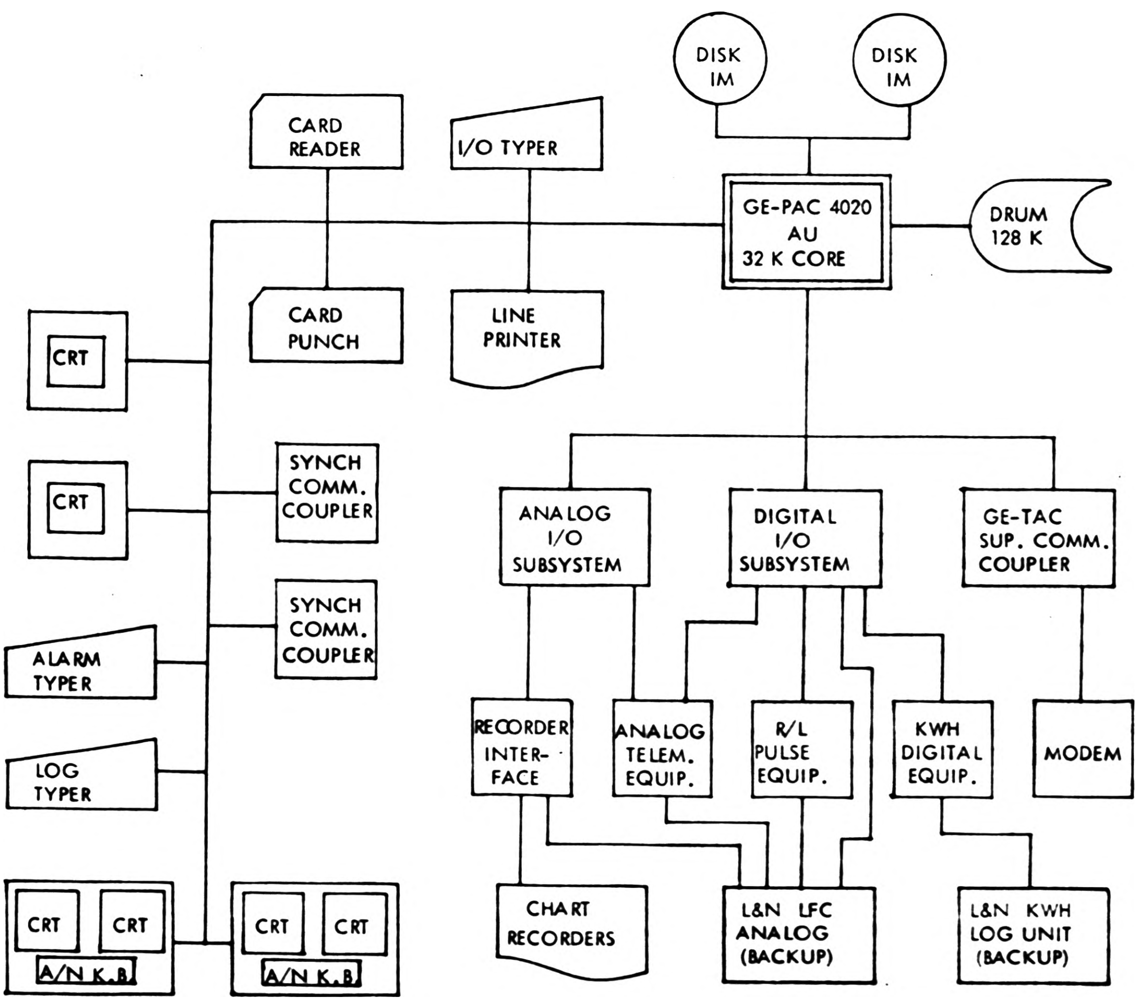
With a simple three-button sequence, the operator can select a display of the scheduled interchanges with any company and schedule type for either yesterday, today, or tomorrow. This display can then be edited to enter or modify any transaction. Through a similar one- or two-button prodecure, a summary of the net system schedules of the net schedules with any company or the net system schedules of any type can also be selected for yesterday, today, or tomorrow.

Additional Memory

The original 24 k core memory has been expanded to 32 k and an additional 1024 k word disk unit has been added. This additional memory provides required capacity for system expan-

Figure 2

THE GE-PAC 4020 SYSTEM BLOCK DIAGRAM



sions and for the development and implementation of new functional software.

G&T Data Links

Two of the member generation and transmission (G&T) coops. (Sho-Me and Central) are installing mini-computer supervisory systems to monitor and control the critical components of their transmission facilities. These new supervisory systems are being tied into the ECS through two 2400 baud, bit-serial synchronous communications links. Through these links, the ECS will acquire data on the operation of these systems for monitoring and display. In addition, the G&T systems will be able to make use of the GE-PAC 4020 resources to perform various analyses and studies from a remote terminal on their computer system.

Dispatcher's Load Flow (500-bus)

The original 127-bus load flow program has been modified to handle 500-buses and 1250 lines. The 127-bus load flow was never used, since its 200 line limitation was not adequate to handle the 126-bus reduced AEC system.

Dispatcher's Energy Log

A new comprehensive dispatcher's energy log is currently being developed. The new log will provide both daily and monthly summaries of all energy transactions, metered energy interchanges, and all system generation, load, and interchange statistics. The data base for the log printer will be accessible from the CRT console for review and editing. Logs will be printed on the line printer on demand.

FUTURE PLANS

In 1971, Associated installed a new digital computer energy control system to improve the reliability and economy of its power system operations because of the increased size and complexity of the power system. Since that time, many additions and improvements have been made to the new control system in response to the definition of new areas for automation and the redefinition of existing functions. Because of the new ECS, the reliability and economics of Associated's power system operations have been improved.

It would be terribly short-sighted at this point, however, to think that the job of power system operations automation is complete. The size and complexity of the power system increases every year. (The AEC system load has been increasing at a rate of more than ten percent per year for several years now, and the trend is expected to continue.) New large generating facilities, new EHV transmission facilities, additional ties with other utilities, and increased loadings on existing generating and transmission facilities will create new requirements for increased system security. Environmental concerns and the recent energy crisis will place new emphasis on system economy and the improved efficiency of energy generation and transmission as well.

Significant advances in the design of control systems and related data acquisition, communications, and display equipment have been made in recent years. Increases in computing power, real-time power system data collection capability, and effectiveness of man-machine interfaces as well as major advances in the formulation and development of new control, monitoring, and security analyses now make it possible to develop and implement advanced energy control systems to further improve the reliability and economy of operations of today's ever increasingly complex power systems.

Some of these advanced energy control system functions which are envisioned to be performed by the Associated ECS in the future are:

1) On-line Short-term System and Bus Load Forecasting
2) On-line Unit Commitment Scheduling
3) On-line Spinning Reserve Determination
4) On-line Power System State Estimation
5) Optimal Power Flow and Direct Economic and Security Dispatch of both Real and Reactive Power
6) Security Analyses based on On-line Load Flow Calculations

A redundant digital backup system, a digital telemetering system, and colored, limited graphics CRT consoles are also envisioned for the future.

Advances in automation technology have been very rapid in recent years, and it is very difficult to predict exactly what the state of the art will be next year, let alone five years from now. For this reason, it is very difficult to predict exactly how the Associated ECS will change in the next few years to meet the new challenges it will face for improved system security and economics. It is safe to say, however, that the evolution of the ECS will continue, and that the quality of power system operations will improve.

Biographical Sketch of Douglas W. Arlig

Douglas W. Arlig was born in Winchendon, Massachusetts, on April 23, 1947. He received a B.S.E.E. degree from Tufts University, Medford, Massachusetts, in June of 1969, and is scheduled to receive a M.S.E.E. degree from Arizona State University, Tempe, Arizona, in May of 1974.

He was employed by the General Electric Company in the Power Systems Automation section of their Process Computer Department in Phoenix, Arizona, as a programmer from June, 1969, to May 1972. He is presently employed by Associated Electric Cooperative, Inc. in Springfield, Missouri, as System Programmer with responsibilities for the maintenance, development, and implementation of automation systems for power system operations.

Mr. Arlig is a member of M.S.P.E. and I.E.E.E. He is also a member of the Power Engineering and Computer Societies of the I.E.E.E.

PART II

ENERGY MANAGEMENT

VII - ENVIRONMENTAL IMPACTS OF POWER GENERATOR STATIONS

CHAIRMAN:
JOSEPH T. ZUNG

ENERGY AND THE ENVIRONMENT

Joseph T. Zung
Department of Chemistry
University of Missouri-Rolla
Rolla, Missouri

The topic of Energy and Environment is probably the most timely one at present time. Probably it is not because both energy and environment are man's most precious resources we want to conserve, but because of their seemingly contradictory and mutually destructive nature. One often asks ourselves these days: Is the energy crisis an environmental problem or environmental restrictions caused our present energy crisis?

The public wants a balance between adequate energy and a clean environment. But, on the one hand, the environmentalists want to preserve our clean environment at all costs, even if it means a collapse of our economic structure; while, on the other hand, the energy producers and consumers are trying to satisfy our hunger for energy without any regards to all the adverse effects created on our environment. The objective of this symposium is to develop a broad-based educational basis that will convince the public that the issue is not energy <u>versus</u> the environment, but energy <u>and</u> the environment. We need to educate people to understand the trade-offs required in matching their needs and desires for energy with their ecological hopes and dreams.

The energy producers and consumers, of course, are equally responsible to preserve our environment as the environmentalists are to promote economic stability and growth. As noted Louis H. Roddis, Jr., vice-chairman of the Board of Consolidated Edison, "I think environmentalists should have to file specific impact statements on the cost of the measures they propose to protect the environment. I am not aware that the public has given an unrestricted proxy to anyone to decide that environmental costs don't matter."

There are many factors contributing to our present energy crisis, but the following are thought to be the major ones:

(1)- Artificial low prices of natural gas, which discourage exploration and development of new sources;

(2)- The availability of foreign oil, which again discouraged development of our vast domestic petroleum reserves and resources;

(3)- The environmental movement, which put increasing pressure on industry to burn clean fuel;

(4)- And, finally, the delays in starting up nuclear power plants, partly because of the intervention of the environmentalists and partly because of the growing pains of a new technology.

Environmental Impacts of Power Generators.

Our concern about polution of the environment has a direct relationship to energy, e.g. all atmospheric pollution is the result of combustion, thermal pollution is usually a by-product of the process of converting heat to electricity through a turbine generator. The adverse effects on the environment are produced whenever heat is used for energy conversion. Since most electricity is produced by the use of heat, increases in the production of electricity mean increases in adverse environmental effects. This in turn focuses the environmental problem on power plants. If we replace all internal combustion engines with the electrically powered vehicles, environmental pollution will be concentrated on power plants.

The electrical demand doubles every ten years. Since installed capacity at the end of 1970 was 340,000 megawatts, to double that capacity in 1980 would require 300 new large power plants, and 600 new plants in 1990. These large plants require great quantities of water for cooling purposes, about 8-12 billion gallons a day! If in 1980 all plants were to use this method, the total flow would equal to 1/6 of the available fresh water run-off.

Most of those who advocate zero growth in population and zero growth in the standard of living do so because of pollution. They demand that we must take immediate steps to stop pollution. But a great many such steps require the use of energy, e. g. treatment of sewage and industrial waste, substitution of electric cars for the present automobiles, increased use of rapid transit in metropolitan areas.

There are two important environmental factors to be considered in planning construction of large power plants:

(1)- The significance of the rate of consumption of nonrenewable natural resources.

(2)- The significance of adverse effects on the environment from the generation of heat by use of each of the fuels available and the adverse effects from the excess heat generated in making electricity.

An ironic phenomenon about the fossil fuels available for production of electricity is that the most plentiful, coal, is the one that pollutes the atmosphere most and that the least plentiful, natural gas, pollutes the atmosphere least. Even the nuclear "fuel" pollutes the atmosphere with radioactive gases.

Nuclear Waste

(1) The use of nuclear energy to generate required electrical power should be conformed with rigid standards in the real interest of improving the environment and public health. The main objective is to eliminate wherever practicable both the volume and radioactivity content of the effluents. The effluent system design objective is that radiation exposure to any member of the public should be well below the internationally accepted radiation exposure limit of 500 mrems per year to any individual.

(2) Since nuclear plants are still less efficient than fossil-fuel plants in utilizing heat, the nuclear plant, for a given unit of electricity, has more exhaust heat to dissipate than has a fossil-fuel plant. Substantially all that exhaust heat is dissipated in water. This dissipation takes place by drawing water from an external source, heating it

and returning it to its source at higher temperature. Under almost all circumstances, the heated water in turn transfers all of the exhaust heat to the atmosphere.

Nuclear Power Plants

With the increase in the total number of nuclear power plants in the U. S. in the next two decades, the problem of controlling releases of radioactive materials to the environment becomes one of our greatest concern.

Liquid Effluent Treatment: With improved techniques, radioactive material discharge can be reduced by maximizing recycling by additional filtration, dimineralization and evaporation of waste sources.

Gaseous Effluent Treatment: The basic gaseous treatment systems should include longer duration tank storage, filtration, and charcoal adsorption before release into atmosphere. To provide a high degree of system reliability, all essential system components must be provided with redundant equipment, leakage must be minimized by a low operating pressure, use of welded pipe.

Environmental Problems Related to Unconventional Energy Sources

(1) Magnetohydrodynamics (MHD)

In MHD, electricity is produced by forcing a conducting ionized gas through the magnetic field, at temperature of about 4000°F. In a closed cycle system, one can eliminate the problem of exhaust gas with its accompanying air pollution potential. But the temperatures involved in a closed cycle are too high for normal materials. In an open cycle, gas is exhausted to the atmosphere. The initial high temperature of the gas combined with a rapid quench in temperature results in a greater concentration of oxides of nitrogen than in ordinary combustion.

(2) Nuclear Fusion

Unless the fusion plant can produce electricity by a direct conversion process, it will be no more than a source of heat with the attendent problems of dissipating exhaust heat. Direct conversion of high efficiency is technically much more difficult than a fusion reaction used only to produce heat.

Fusion plants also have the same problems of radioactivity containment and disposal of waste. In a fusion process, a substantial quantity of radioactive tritium would be generated, estimated at 100,000,000 curies at any given moment in a medium to large size fusion plant. Beside there would be an intense flux of energetic neutrons that would induce radioactivity in various materials, thus creating problems of replacement of contaminated material and its disposition.

(3) Geothermal

First, there is the same thermal exhaust problem as with a fossil-fuel fired power plant. Second, the tapped energy is hot water under pressure. When the pressure is reduced, most of the water flashes into steam, leaving behind a residue - brine, silica, various metals - which must be disposed of.

(4) Solar Energy

No environmental pollution except that, for generation of electricity, it would require an area of 16 sq. mile to collect enough solar energy to convert to 1000 megawatts of electricity. (The Solar Farms Concept.) Even with a new means of collecting solar heat, a 1000 megawatt power plant in the sun-drenched Southeast would still require 3 sq. miles of collector area. (~ 1920 acres).

THE ASSESSMENT OF ENVIRONMENTAL IMPACTS AT NUCLEAR POWER GENERATING STATIONS

Thomas H. Row and J. R. McWherter
Director Task Group Leader

Environmental Statements Project
Oak Ridge National Laboratory, P.O. Box X
Oak Ridge, Tennessee 37830

ABSTRACT

The Federal actions that are required with regard to nuclear power stations are the granting of a construction permit and later the issuance of a license to operate the station. Since the Atomic Energy Commission (AEC) is responsible for these actions, the Commission is also responsible for preparation of an environmental statement on the proposed actions. The National Laboratories including the one at Oak Ridge are used as part of the staff in preparing the statements.

The staff makes an independent determination of the plant effluents and their dispersions. The impact of these and plant construction on the environment are assessed by the staff. Alternatives to the proposed plant are similarly evaluated as are alternative subsystems such as the proposed waste heat removal system. Finally the environmental costs are compared with the benefits.

A number of assessments have resulted in required changes in heat removal systems, chemical treatment procedures and radioactive waste systems to reduce the impacts to an acceptable level. The benefits of the modified stations have been shown to outweigh the environmental costs.

HISTORY OF SO_2 REMOVAL SYSTEM AT THE MERAMEC PLANT OF UNION ELECTRIC

Gerald E. Dreifke
John F. McLaughlin
Jerrel D. Smith

Union Electric Company
St. Louis, Missouri

ABSTRACT

In line with the then emerging air pollution control regulations Union Electric installed a limestone injection wet scrubber sulfur dioxide removal system on an intermediate size coal-fired utility boiler at its Meramec Power Plant on an experimental basis in September, 1968. During approximately 3 years of operation many difficulties were encountered with plugging and scaling of various system components by calcium sulphate. As a result of this experience along with related experiences by other utilities employing similar systems, the experiment was terminated in June, 1971.

As a result of the experiences gained, however, second generation experiments in sulfur dioxide removal have been initiated elsewhere with the hope of improved performance. A number of experimental projects are still under tests. Costs in resources, reliability, and disposal of residual by-products are matters of great concern.

The true cost of sulfur dioxide removal systems in dollars and resources is not well known and perhaps a reevaluation of current and future SO_2 removal projects is in order at this time before additional resources are committed.

UNION ELECTRIC EXPERIENCE

As air pollution control regulations were emerging during the mid 1960's Union Electric Company recognized the need for research work to develop some method of removing sulfur dioxide from the stack gases of large power plant boilers. As a result of discussions with potential suppliers of such equipment Union Electric Company decided in 1967 to install a Combustion Engineering limestone boiler injection wet scrubbing sulfur dioxide removal system on an intermediate size coal-fired utility boiler at the Meramec Power Plant. The system was installed and began operation in September, 1968, and operated intermittently until June, 1971. The total operating time during that period was 120 days equivalent. During that time many difficulties were encountered with the system including such problems as:

1) Plugging of the boiler economizer, superheater, and air heater with lime and calcium sulphate deposits.

2) Scaling in the wet scrubber and pipes due to supersaturated solutions of sulphates.

3) Demister and stack gas reheater plugging due to liquid carry over from the wet scrubber which contains sulphates and fly ash.

SOME OTHER SYSTEMS

The flurry of regulatory activities prompted others to become interested in the development of other types of scrubber systems. A somewhat similar scrubbing system was installed at the Lawrence Plant of Kansas Power and Light. This system operated intermittently for some period of time with substantial difficulties. However, it was not until a second unit was placed in service at the station that the combined discharge from the scrubber units resulted in saturation of the recycle water. At that time major scaling problems began to occur in both Lawrence scrubbing systems, and the history of the Lawrence problems is much the same as those experienced at Union Electric.

Kansas City Power and Light Company installed two boiler injection limestone scrubbing systems at their Hawthorn Power Station which experienced the same type of problems.

This cumulative experience has led Union Electric to conclude that limestone boiler-injection systems are not practical for removal of SO_2 from the stack gas; however, the experience has been valuable in the design of second generation scrubber systems which utilize lime/limestone slurry injection directly into the flue gas scrubber container itself.

Numerous processes are now under study. To date the Environmental Protection Agency reports that there are some 44 systems in operation or committed in the United States.[1]

The types of systems under study to date are:

1) The lime/limestone wet scrubber throw away systems.
2) The magnesium oxide scrubber regenerative system.
3) The alkali scrubber regenerative system.
4) Catalytic oxidation system.
5) Carbon Absorption System.

The most promising operations to date are those utilizing lime materials as an absorbant.

Data

When Union Electric began its developmental work it envisioned a scrubber design that would operate with a reliability equal to that of the other major components of the power plant equipment and that the cost of such systems would be reasonable. The Union Electric scrubber installation cost approximately \$10 per kW of unit plant capacity and, at the time the subject system was installed, it was estimated by vendors that a similar system could be installed on a new 500 MW unit for about \$5 or less per kW.

In a 1972 document published by the Federal EPA in connection with final promulgation of "Standards of Performance for New Stationery Sources", it was stated that the cost of the lime scrubbing system which is now in operation at the Paddy's Run Plant of Louisville Gas and Electric would be \$28.6 per kW of plant capacity.[2] The final cost of that system which went on line in 1973 has been reported to be \$57 per kW.[1] In the 1972 document it was reported that the Will County Station limestone scrubber system of Commonwealth Edison would cost \$49 per kW.[2] The final cost of that installation was reported to be \$108 per kW.[1]

Testimony submitted by an equipment vendor at hearings held by the Federal EPA in October and November 1973 on power plant compliance with sulfur oxide air pollution regulations indicated that their ratio of installed cost to vendor to the selling price to user of such systems was 3.02.[3] (This ratio is usually less than one.) This reflects the difficulty of estimating costs of scrubber equipment for which operating reliability has not yet been demonstrated and raises the question of what one might expect such equipment to cost once all the design problems have been identified and solved.

Operating Experience

Brief statements about operating experiences of three wet scrubber installations follow.

The operating experience of the Will County System as of December 31, 1973 has demonstrated a reliability on ½ of the scrubbing system of 27% and on the other ½ of the system 13%.

Louisville Gas and Electric's 65 MW Paddy's Run No. 6 is a peaking unit utilizing waste carbide sludge for SO_2 removal. Combustion Engineering designed the system to include two scrubber modules each consisting of two marble bed contactors in series. The scrubbers were started up on April 5, 1973, however, various modifications were required before attaining improved reliability during late 1973.

Use of natural gas in the direct fired reheater has avoided the corrosion problems prevalent in reheaters of other SO_2 removal systems. Availability and economics of natural gas for reheat may be of small consequence on a 65 MW peaking unit but become a major factor of consideration for large base loaded installations.

Because of poor turn-down of the scrubber, Louisville Gas and Electric is recycling gas to keep gas flow up to design load. In large multiscrubber SO_2 removal installations gas flows probably will be regulated by dampers. Demonstration of reliability for critical damper operation is not part of the development program at Paddy's Run and hence this aspect of development of reliable hardware requires additional study.

Although the operating results to date have been encouraging, a longer period of trouble-free operation on the Paddy's Run Unit is required to determine system reliability.

On July 9, 1973, two of Duquesne Light's Phillips Station single stage venturi scrubbers were placed in operation for particulate removal only. At that time the lime addition system was not yet complete. Consequently the unintentional SO_2 removal in the particulate scrubber resulted in low pH which could not be corrected. Corrosion problems were numerous and affected pumps, duct expansion joints, concrete stack, I.D. fans, inlet dampers and stiffner bars. As of February, 1974 no sulfur dioxide removal had yet been attempted.

Operational data on many of the systems now being experimented with in the United States and abroad is not readily available.

Environmental Consequences

There are other potential environmental problems created through the operation of sulfur dioxide stack gas removal systems. For example the volume of sludge generated by throw away systems is substantial. If Union Electric were to install a lime wet scrubbing system on its 880 MW Meramec Plant the sludge generated would fill 100 acres of land to a depth of about 3 feet each year. The reader could easily project this data for a thirty year life at Labadie which has a capacity of 2400 MW.

Work has been carried out by Chicago Fly Ash to "fix" the sludge generated at the Commonwealth Edison Will County Plant and preliminary studies have been conducted by Dravco to manage sludge generated at the Duquesne Power and Light Phillips Station. It is reported that sludge preparation costs at Will County are approximately \$17 per ton of dry product and the cost to prepare the sludge for landfill at the Duquesne Power and Light Plant is estimated to be \$14-\$15 per ton of dry disposable product.[1] The cost, therefore to prepare sludge for landfill by these methods would add nearly 5 million dollars per year to the operating budget of a 1000 MW coal-fired plant, which would be about 10-15% of environmental control costs of SO_2 removal.

TVA has done considerable work on SO_2 emissions and the following excerpts are from their news release of February 5, 1974 on this subject.

> "The basic problem with chemical scrubbing as a means of controlling sulfur dioxide is not confined to the technology of using it in power plants.
>
> "Scrubbers themselves create new environmental problems of immense proportions which have not been solved. Foremost among these is the problem of solid waste disposal. The waste created by a power plant using the scrubbing process requires four times as much land for disposal as fly ash. For TVA, this would require disposal areas totaling 20,000 acres in the next 20 years. The waste sludge material is watery and unstable. It is therefore not suitable for other uses and poses the danger of water pollution.
>
> "In addition, the process would impose large new burdens on the Nation's energy supply. In TVA's case, scrubbers on all its plants would consume 6 percent of the generation of those plants, requiring an extra 2.4 million tons of coal, the equivalent of 10 million barrels of oil. They would require mining 25 percent more minerals--coal and limestone--with all the environmental problems and additional energy required for mining and transportation."[4]

BACKGROUND INFORMATION FOR PROPOSED NEW-SOURCE PERFORMANCE STANDARDS

The U. S. Environmental Protection Agency published a document titled "Background Information for Proposed New-Source Performance Standards" dated August, 1971 which states:

> "At this time only the lime-slurry scrubbing system is considered adequately demonstrated on large

steam generators. Three other processes have been shown capable of continuous operation at smaller installations."

"A lime-slurry scrubbing system, demonstrated for 6 months on two coal-fired units of 125 and 140 MW capacity, approached the SO_2 emission limit of 1.2 pounds per million BTU."[5]

At the time that document was prepared the Union Electric APCS had been permanently shut down, yet EPA went on to use the document to support regulations on "Standard of Performance for New Stationary Sources". In addition, EPA published a supplemental statement in connection with final promulgation of those regulations in the March 21, 1972 edition of the Federal Register where on page 5768, Table-I shows that the Union Electric APCS "Operated at 73% efficiency during EPA tests".[6] To our knowledge, EPA has never run tests on the Meramec Air Pollution Control System.

The tremendous administrative burden placed on the Federal EPA by the Congress in passing the Clean Air Act is certainly recognized. However, EPA went on to promulgate emission standards which cannot be met and, indeed, which are not compatible with the needs for improving air quality in areas where the quality of the air is already below State and Federal ambient standards. Compliance with arbitrary emission standards under such circumstances results in consumption of scarce resources without providing corresponding benefits to the public.

SUMMARY

The atmosphere was not pristine pure before man's existence on this earth and it would not become so if life became extinct. There are many natural forces at work which result in substantial releases of "pollutants" such as: volcanic action, decay of vegetation which releases sulfur compounds, sulfur compounds released into the air in the form of sea spray, etc. Therefore, our efforts must necessarily be directed to maintain air quality at acceptable levels using wisely the resources available to us.

It is obvious that the true cost of sulfur dioxide systems is yet unknown and it would seem that we need to reevaluate the wisdom of requiring installation of such systems under circumstances where ambient air quality is already better than required to protect the health and welfare of the general public. A review of the social costs and benefits of applying control systems indiscriminately should be undertaken which takes into consideration alternative resource application.

The cost to install sulfur dioxide scrubbers on the three major coal-fired plants now in operation in the Union Electric System would be staggering. It is estimated that the investment required for such a program would be on the order of $400,000,000 and would result in an increase in revenue needs of about $100,000,000 per year. This would result in average power cost increases of about 25%.

There are a variety of ways to control air quality, such as the use of tall stacks for good dispersion, intermittant load reductions when necessary to prevent pollutant build-ups under certain adverse meteorological conditions, use of low sulfur fuels, and in the future, application of emission control devices when they are fully developed and when they become the best alternative method of ambient air quality control.

It seems clear that the time has come for a new look at our air quality control programs and the Clean Air Act itself, in order to make essential corrections which will provide acceptable air quality at the least social and economic costs to the general public.

REFERENCES

(1) "Report of the Hearing Panel - National Public Hearings for Power Plant Compliance with Sulfur Oxide Air Pollution Regulations".

(2) "Standards of Performance for New Stationary Sources - Supplemental Statement in Connection with Final Promulgation" CFR, March 21, 1972.

(3) Environmental Protection Agency Public Hearings and Conference on Status of Compliance with Sulfur Oxide Emission Regulations by Power Plants and Application of Sulfur Oxide Control Technology - October 24, 1973, Page 1288 of the hearing record.

(4) TVA News Release of February 5, 1974, TVA 4516 (3-72).

(5) "Background Information for Proposed New-Source Performance Standards", U. S. Environmental Protection Agency, August, 1971.

(6) Federal Register, March 21, 1973, Table I, Page 5768.

INTERFACES OF STEAM ELECTRIC POWER PLANTS WITH AQUATIC ECOSYSTEMS

Gerald J. Lauer William T. Waller Guy R. Lanza

New York University Medical Center
Laboratory for Environmental Studies
New York, N.Y.

SUMMARY

Growth and reproduction may be stimulated by increased temperature in the cooling system and thermal plume during seasons when ambient water temperature is less than optimum, but growth, reproduction and survival are reduced when the elevated temperatures become excessive. Some fish species congregate in the warm thermal plumes during cold seasons but are excluded from this living space by temperatures above their preference in the summer. However, the warm refuge provided by a thermal plume in cold seasons can be a death trap if a power plant shuts down suddenly and exposes the fish to cold shock exceeding their lower thermal tolerance limits.

Each of the factors tend to affect different segments of the biota. For example, impingement involves primarily juvenile and adult life stages of fish and species of large invertebrates; pumped entrainment affects are restricted to the smaller planktonic forms that include egg and larval stages of fish; and chemical and thermal discharges may affect all segments of the biota but in ways that vary dramatically among segments, species or even life stages of a species.

Death and injury of aquatic organisms by power plant operations is a non-consumptive form of cropping, in that dead and injured specimens are returned to receiving waters and can be utilized by various trophic levels.

Mortality of aquatic organisms, and stresses resulting in changes not manifested in mortality imposed by power plant operations do not necessarily cause detectable adverse effects on populations in receiving waters. This fact has been demonstrated by a considerable number of studies at existing plants. However, fairly extensive damage to aquatic biota in the vicinity of a relatively few power plants also indicates that there are local and ecosystem-wide limits on the electric generating capacity that can be sustained without significant adverse effects on aquatic life.

Aquatic populations have natural but limited capacities to withstand predation and other forms of stress before significant damage results. In fact, many if not all species require some level of cropping in order to sustain healthy, productive populations.

Aquatic populations are known to compensate for cropping by various mechanisms that include increased growth rates, reproduction rates, and survival rates. As a result, cropped laboratory populations of some species are known to sustain annual production rates as much as 10 to 20 times higher than uncropped populations. But populations in natural bodies of water are already subjected to cropping by other animal species, and by man in the case of many fish species. The ultimate question for which answers must now be sought is, how much additional cropping by power plant operations can aquatic populations sustain without significant damage to the populations?

Both types of cooling systems (closed and once-through) involve construction effects, and interface with aquatic life at the water intake structure, in the cooling system (pumped entrainment) and at the discharge plume. The closed systems withdraw much less water, so expose many fewer organisms to risk of impingement and entrainment than do the once-through systems. On the other hand it is generally assumed that all organisms entrained into closed cycle systems are killed compared to mortality estimates ranging from 2% up to 100% for organisms entrained through various plants with once through cooling systems. The once-through systems discharge much more heat, that may or may not cause significant adverse effects, but utilize much more of the assimilative capacity of the receiving water than closed cycle systems. Consequently, closed cycle cooling systems permit installation of much more generating capacity on a body of water. On the other hand closed cycle systems consume considerably more water by evaporation, an important consideration in areas already faced with water shortages, and they cost much more than once-through systems. There are also esthetic and terrestrial environmental effects associated with closed cycle systems.

Research to evaluate adverse effects of steam electric power plant operation on aquatic life has focused almost entirely on the discharge plume of heated water. Recently, many investigators have become convinced that potential for adverse effects by the thermal plumes may be relatively inconsequential compared to impingement and pumped entrainment. Most legislation and regulatory effort is still focused on thermal discharge from power plants but consid-

eration of impingement, pumped entrainment and other environmental effects is increasing rapidly.

Clearly plant design and regulatory efforts to minimize adverse environmental effects of power plant operations should involve an integrated analysis of the effects of all interfaces for all existing and proposed power plants on a body of water relative to the costs and benefits likely to be achieved by abatement efforts. Utility management and regulatory agency decisions based on a piece-meal approach and inadequate information may result either in unacceptable environmental impacts or unwarranted capitol expenditures.

INTRODUCTION

Steam electric power plants use large amounts of water for cooling the condensers and auxiliary systems, and for boiler feed make-up, maintenance cleaning, wet ash handling systems, air pollution control devices, intake screen backwash and disposal of sanitary and chemical wastes.

The cooling water requirements for steam electric plants in the United States now amounts to about 60 trillion gallons per year, which is roughly equivalent to 15% of the total flow in U.S. rivers and streams. Other industries use an additional 10 trillion gallons of water per year for cooling (1).

A nuclear fueled plant requires from 40 to 50 percent more cooling water flow than a fossil-fueled plant of the same generating capacity and condenser cooling water temperature rise (ΔT) design because a nuclear plant rejects from 40 to 50 percent more heat to the cooling water per killowat-hour (KWh) than a fossil-fueled plant. Fossil fueled plants reject from 10 to 20 percent of their waste heat through the stacks to the atmosphere and have a higher thermal efficiency (39% for a well - designed, well-run plant) than nuclear-fueled plants. Nuclear plants reject virtually all of their waste heat to the condenser cooling water and have thermal efficiencies that seldom exceed 34% even under ideal conditions. Thus a 600 MW fossil-fueled unit operating at capacity may require about 600,000 gallons/minute of cooling water heated to 9 degrees centigrade (15-16 degrees F) above ambient compared to about 840,000 gallons/minute heated to 9^{o}C for a 600 MW nuclear unit.

The water requirements for auxillary uses vary widely, depending upon plant design, from a few hundred to about 1000 gallons per minute per 100 Megawatts of generating capacity.

Steam electric power plants employ two basic types of cooling water systems, once-through and closed, along with a host of supplemental modifications and combinations of those systems.

Once-through systems withdraw water from a source, pump it through the condensers one or more times, and then discharge the heated water back to the source.

Closed cycle systems pass the heated water from the condensers through cooling ponds, canals or cooling towers where the excess heat is rejected to the air, before the water is again recycled through the condenser cooling system. After initial filling of the cooling system the only additional water required is the amount necessary to make up for losses by evaporation, to dilute concentrated dissolved solid and chemical discharges from the cooling system and to service auxiliary systems. Some plant designs provide for cycling the service water through the closed cycle cooling system, which reduces the amount of water required from source bodies of water. In general the use of closed cycle cooling systems reduces the water requirements of a plant to about 3 to 10 percent of the amount required for once-through systems. The amount over about 2.5-3% consists of service water not treated in the closed cycle cooling system.

Both types of cooling systems interface with aquatic life at the water intake structure, in the cooling system (pumped entrainment) and at the discharge plume. Other factors that may cause power plants to impact on aquatic ecosystems include construction, spillage of coal and oil during unloading operations, scouring by tug boat traffic, leaching from coal piles, discharges from fly ash ponds, and discharge of chemical and sanitary wastes.

Site Selection and Facility Design

Site selection and facility design are planning functions that do not of themselves cause aquatic impacts, but site selection and design decisions substantially determine the kinds and degree of impacts that will result from construction and operation. A wholistic appraisal and balancing of environmental consequences of alternative sites and designs can minimize the aquatic impacts, but it is technically impossible to achieve an impact-free power plant facility.

Construction Impacts

Construction activities that affect aquatic ecology include excavation both on land and in the water required to build the facility. Erosion of silt from land excavations into adjacent waters may smother benthic organisms and fish eggs and produce turbid conditions that inhibit primary production by phytoplankton and rooted aquatic plants. Damage to aquatic life and habitats by this factor can be minimized by careful selection of the site and construction methods, and specific control and abatement techniques.

Excavation directly in water bodies for the purpose of constructing intake and discharge structures, diffuser pipes, docks, bulkheads, jetties and other such structures affect aquatic life in various ways.

Benthic organisms are most vulnerable. A large fraction of those in the dredged material are likely to be killed. Many species of organisms inhabiting the bottom in the vicinity of the dredged area are likely to be killed or damaged by siltation, which is especially difficult to control at underwater excavations. The time required for bottom habitats to return to pre-excavation condition depends both on the effectiveness of post construction rehabilitation efforts and natural recovery processes. Recovery by natural processes tends to take much longer in low flow velocity waters such as lakes and coves where sediment and drift-organism transport is normally more dynamic.

More motile organisms will differ in their reactions to dredging operations. Some animals such as fish and large crustaceans may leave the area during construction and would probably return later. Others might not react or might move into the construction area to feed on organisms exposed by the dredging. In general, these motile organisms should be able to avoid any adverse impact.

Planktonic species could experience a short term impact as a result of shading effects from material suspended in the water column.

Impacts of excavation are generally transitory, but are one of the environmental trade-offs to be considered when choosing from among cooling system alternatives.

Hard under-water surfaces of installed structures provide many species with suitable habitats that are frequently in short supply. These structures also provide a haven for many species of fish that prefer to live around submerged objects. Indeed, this tendency for fish to be attracted to submerged objects is one of the reasons why pre-construction biological surveys are frequently of limited value for evaluating potential fish impingement on intake screens, the next subject for discussion.

Impingement of Biota on Intake Screens

Aquatic organisms, mostly species of fish and a few invertebrates, too large to pass through the mesh of cooling system intake screens are subject to being impinged on the screens. Many of these impinged organisms are severely injured or killed.

Trash racks made of a series of vertical steel bars approximately 2 to 3 inches apart and vertical traveling screens developed in the 1920's are still the major equipment used for removing trash from the cooling water before it is pumped through the condenser system. The traveling screens of most stations in the U.S. are made of 3/8 inch square mesh. Figure 1 shows two basic types of intake structures used at steam electric power stations. Many modifications of these are also in use.

Both designs illustrated have traveling screens recessed some distance "downstream" of the opening into the intake structure, a feature common to many existing cooling water intakes that is conducive to trapping of fish and large invertebrates until they tire of swimming against the intake flow velocity and become impinged on the screens. Placement of the screens at the front of the intake canal opening precludes entrapment in the canal.

Because vigorous monitoring has been done at only a few plants during the past three or four years adequate records are scant, but fish impingement on cooling water intake screens of steam electric stations has almost certainly grown in proportion to the increase in the number and size of the stations and intake structures.

Twenty years ago when most units were smaller than 200 $MW_{(e)}$ fish losses probably were relatively small. Until very recently the station operator's major concern was that, occasionally, impingement of large numbers of fish might block passage of water into the cooling system or crush the intake screens and require shutting down the plant. Now utility management and regulatory agencies must give considerable attention to environmental implications of fish impingement on intake screens.

Fish impingement is becoming a pivotal environmental issue in the licensing hearings for many new units. Unfortunately, information on the host of factors that appear to influence the rate of fish impingement on intake screens is grossly inadequate for making reliable predictions of the kinds and quantities of fish likely to be impinged at proposed intake structures.

The abundance, temporal and spatial distribution, and behavior of fish relative to the location and design of intake structures are likely to be important factors. The species composition, abundance and spatial distribution of fish populations at any given location are known to vary at different times of the day, seasonally and annually because of species specific differences in habitat preference, reproductive cycles migratory patterns and response to a host of physical, chemical, hydrological and biological variables.

Indian Point Unit 1 on the Hudson River estuary has been intensively monitored for fish impingement data during the past 4 years. Fish impingement is one of the vital issues in the controversy as to whether the present once-through cooling system should be replaced with closed cycle cooling towers.

The numbers of fish impinged is extremely erratic, an observation that probably applies to most other power station intakes. The rate of impingement is very low for extended periods of time, then suddenly, large numbers of fish are collected on a single day. It is not uncommon for over 90% of the annual fish impingement to occur in less than 10% of the time. Adjacent intake structures only a couple of feet apart frequently collect dramatically different numbers of fish. There appears to be some correlation between sporadic high impingement rates and intrusion of saline water into the area of the Indian Point plant.

An apparent substantial reduction in the number of fish impinged at Indian Point by reducing the average flow velocity approaching the screens to 0.5 feet per second or less has often been cited as an intake structure design criterion that will prevent fish impingement. In fact, many fish continue to be impinged on the Indian Point station intake screens at that calculated approach velocity. In any case the observed reduction in fish impingement might well have been caused by the reduction in flow volume rather than the reduced approach velocity that was accomplished by reducing the cooling water flow volume.

A relatively small number of species constitute the bulk of the fish collected at the Indian Point intake screens. White perch, striped bass, tomcod, blue-back herring and the bay anchovy are the principle species involved. The relative abundance of fish species collected on the screen is different than the species composition taken in gear in the immediate vicinity of the plant. This indicates either that some species are much more prone to impingement than others, or that species composition in the estuary is not accurately measured by the gear employed. Definite seasonal variations have occurred in the species collected on the screens.

Based on the assumption that new Indian Point units (2 and 3) will impinge fish at the same annual rate per unit volume of flow as the existing Unit No. 1 and the additional liberal assumption that three units would run at full capacity every day of the year, Consolidated Edison (2) projected annual fish impingement for Indian Point as follows:

	Number	Weight (lbs)
Unit 1	372,863	4,089
Unit 2	1,118,584	12,263
Unit 3	1,118,584	12,615
TOTAL	2,610,031	28,615

Published accounts of the large numbers of fish impinged on the Indian Point intake screens have frequently prompted the suggestion that a commercial processing operation ought to be established to make use of the fish. However, most of the fish impinged by the Indian Point plant are 2 to 4 inches long, so that the total annual weight of fish (28,615 lbs) projected to be impinged is far less than needed to support a commercial processing operation.

Sound, electrical fields, bubble screens, light and velocity have been tried at various locations in the United States in attempts to repell or guide fish away from water intake structures. With few exceptions these trials have been unsuccessful. Frequently, initial success has soon been followed by failure as fish rapidly adapted to the stimulus. In other cases the stimulus has been effective for some species but not others. Reduction of intake flow volume and velocity would appear to be effective measures for reducing the numbers of fish impinged on intake screens. Indeed, considerable attention has been focused on the swim-speed capability of fishes in relation to intake flow velocity, the theory being that if fish can swim faster than the intake velocity they will do so to avoid impingement. There are dramatic examples to the contrary, such as the large numbers of white perch that are impinged at Indian Point despite the fact that they can swim faster than the intake velocity. These examples illustrate the importance of fish behavior as a factor.

Screens still appear to be the most effective and reliable means of keeping fish out of water intakes. Considerable research and development effort on new screens and intake structure designs is in progress (1) (3). Much additional information is needed on the many factors involved with fish impingement, including the extent to which fish populations can compensate for losses by impingement.

<u>Pumped and Plume Entrainment Impacts</u>:

Organisms small enough to pass through intake trash screen are pumped through the cooling water systems of power plants. These pump-entrained organisms are exposed to abrupt changes in temperature, hydrostatic pressure, mechanical buffeting, velocity shear forces, and chemicals introduced to the cooling systems by the plants.

Organisms contained in receiving water entrained into discharge plumes (plume entrainment) are exposed to elevated temperature, discharged chemical residuals and velocity shear forces, but these potential stresses are reduced as dilution and dissipation progress.

Organism groups subject to entrainment include planktonic bacteria, phytoplankton, zooplankton, and the planktonic eggs and larvae of invertebrates and fish. These groups differ greatly with respect to abundance, reproductive strategies, generation time, trophic or food-chain function, and other life processes.

The spatial distribution of these potentially entrainable organisms is notably uneven. Distributions are clumped and are subject to change on diel, seasonal, and yearly cycles. Life stages critical to population maintenance may be subject to entrainment only for short periods of the year--periods that may or may not coincide with operating conditions that would cause substantial damage to that life stage. This is true for striped bass eggs and various life stages of other species that move with the salt front in estuaries. The probability of being entrained may vary considerably from one life stage to another, at different ages within a life stage, or among species, depending on where they are in the river and in the water column relative to the location of the cooling water intake and the discharge plume.

Temperature Stress

Water temperature, in conjunction with light, flow velocity and many other interacting biotic and abiotic factors, has a pervasive influence on the composition, behavior and function of biological communities. Aquatic organisms with the exception of mammals have body temperatures almost identical to the temperature of the water they inhabit. The natural temperautres of surface waters in the United States vary from about 32°F to over 104°F depending on the season, latitude, altitude, time of day depth and circulation of water, etc. Surface water temperatures vary with air temperature, and tend to be much more variable in the temperate zone than in either the tropical or arctic zones.

For a given set of physical and chemical conditions, organisms have upper and lower thermal tolerance limits and an optimum temperature range for growth and reproduction. Over time, species have evolved with different ranges of optimal temperature. Some are restricted to cold water conditions such as found in the Arctic and Antarctic zones; and in the deep,cold water of thermally stratified lakes and reservoirs of the temperate zone. Other species prefer warm water habitats such as hot springs. Most species, however, thrive in an intermediate range.

The optimum temperature range is typically closer to the upper range of tolerance for species in surface waters that experience relatively small variation in temperature such as in the sub-tropical and tropical zones, than in temperate zone waters that experience more variable temperature. The assemblages of species in aquatic communities usually contain some species that are relatively prominent throughout the year, and considerable numbers of species that become prominent only during the spring summer or fall in response to seasonal changes in temperature and other prime requisites for growth and reproduction. As a result there is a seasonal succession of species that carry on each of the basic trophic (food-energy flow) functions such as primary production, herbivore consumption, carnivore consumption and decomposition of wastes and detritus.

For this and other reasons, the ultimate consideration of temperature effects on biota must be evaluated at the community or ecosystem level in conjunction with the structure and functioning of the ecosystem. In short, adverse effects on individual organisms or even a species may be insignificant if other species move in to fill the same trophic function in the community, unless the adversely affected species have some special value to humans other than its trophic function in the ecosystem.

Natural temperature variations create conditions in the aquatic medium that are optimum at some times, but in general are above or below the optimum for physiological behavioral and interspecific competitive functions of the biota present. It follows that, "to label any thermal increase in a water body as pollution, regardless of season or other consideration, is to strike a misleading oversimplification. Rather, temperature exerts effects, which alone or in concert with most other environmental factors (including time), may yield results that are favorable or unfavorable to particular human interests. Only when they are clearly unfavorable are we justified in asserting pollution" (4). The mean design ΔT among existing units in the United States is 15°F, with most units being included in the range from 10 to 20°F (5). The calculated transit time (exposure time) from the condensers to discharge back to the receiving water is less than 5 minutes for most existing units, but may extend to 30 minutes or even several hours in the case of a few units (Figure 2).

One of the more notable aspects of the temperature response of aquatic species is the very small difference (about 2 to 3°C) between their upper safe temperature and 100 percent lethal temperature for a given exposure time (Figure 3). The importance of exposure time is illustrated by the fact that a temperature that kills 100 percent of the test organisms in 60 minutes is a safe temperature if the exposure time is 5 minutes or less (Figure 3).

Predicted levels of damage to entrained organisms have usually been much higher than actually found by direct observation. Most of the estimates in the literature have been derived from test exposure times in excess of 24 hours, whereas the transport times (exposure time) from the condensers to the receiving waters for most power plants is less than 30 minutes, and exposure times to temperature elevations more than a few degrees above ambient for organisms entrained into the discharge plume is usually less than an hour.

The time-dose aspect of organisms' tolerance to temperature has long been recognized, but biologists got "locked in" to the procedure of running temperature tolerance experiments for 24, 48 and 96-hours because those times were adopted for standard methods.

Studies conducted in our laboratory during the last 2 years reveal that aquatic organisms can generally tolerate considerably higher temperatures for short periods of time than would be predicted from standard bioassay exposures. For example, the 48-hour TL_{50}* for Gammarus sp. was approximately 5°C lower than the 60-minute TL_{50} at an ambient temperature of about 25°C (Figure 3).

Ambient temperature has been shown to exert a profound effect on the thermal tolerance of an aquatic organism. This is illustrated by the temperature tolerance data

* The 48-hour TL_{50} is the temperature that causes 50 percent mortality of the test organisms by the end of a 48-hour exposure time.

for Gammarus determined over most of the ambient temperature range of the Hudson River estuary (Figure 4). These data indicate that Gammarus sp.can tolerate approximately 11°C higher temperature in the summer than during the winter but Gammarus sp. can tolerate a greater temperature change ΔT in the winter (approximately 22°C for 30 minutes) than in the summer (approximately 11°C for 30 minutes).

The "decay rate" of elevated temperatures in discharge plumes to within 3 to 4°F of ambient temperature varies considerably, depending on the rate and amount of dilution affected by natural and induced mixing (Figure 2). Exposure times to the higher temperature elevations in the near-field portions of the plumes are usually momentary for plankton and larger invertebrates that drift through plumes,but may be prolonged for the more resident benthic organisms and for fish that can maintain position at preferred elevated temperatures in the plumes. Exposure of plankton and drift organisms to low temperature elevation (4°F or less)in the far-field portions of plumes tend to be more prolonged than in the near field.

Keeping in mind that there are often important exceptions to generalizations one might make about the effects of thermal discharges on aquatic life, and that these exceptions must be dealt with on a site specific basis, attempts to generalize do nevertheless help to provide important perspective.

With very few exceptions, existing information indicates that species and populations of plankton and drift organisms in temperate zone surface waters tolerate the time-temperature elevation conditions encountered in the cooling system and thermal plumes of most power plants during the winter, when ambient temperatures are below 4-5°C. The usual effect of the elevated temperature exposure under these ambient conditions is to stimulate metabolism and growth. However, the growth that results from this stimulation appears to be slight because of the shortness of exposure time to elevated temperature relative to the generation times for most species during these low ambient temperature conditions.

Benthos and periphyton subject to more prolonged exposure to elevated temperature exhibit increased growth and species diversity during the winter, spring and early summer, until the elevated temperature exceeds about 30°C. Further increases in temperature above 30°C become inhibitory to increasing numbers of species subjected to prolonged exposures. However, maintenance of natural seasonal cycles of temperature is important for some species that require a winter diapause to initiate reproduction in the next season. Also, fish and possibly other organisms that remain in the elevated temperature long enough to become acclimated to it may be killed by cold shock in the winter if the supply of heated water is suddenly cut off by a shutdown of a plant, and the lower thermal tolerance of the organisms are exceeded.

The relationship of temperature tolerance to ambient temperature is linear. These data are valuable as predictive tools for estimating entrainment mortalities when superimposed over ambient and discharge (projected) temperatures. Figure 5 illustrates the effects of exposure time and ambient temperature on the temperature tolerances (TL_{95}) of two Hudson River invertebrates. Analysis of these data reveals projected mortalities of Neomysis americana during an 8.33°C ΔT at ambient temperatures exceeding 22°C. Gammarus sp. should be able to tolerate the projected ΔT at all ambient temperatures. Direct observations of entrained organisms have generally been in close agreement with our predicted levels of temperature induced mortality based on laboratory temperature tolerance tests.

Many investigators have become distrustful of the predictive accuracy of temperature tolerance data from laboratory assays. However, we have found that laboratory assay tests designed to closely simulate actual time-temperature conditions encountered by entrained organisms produce data which permit quite accurate predictions of mortality by excessive temperature.

The transitory (less than 5 to 30 minute) exposure to ΔT's in the cooling system and the near-field portion of plumes begin to cause damage and death of more temperature sensitive warm-water species of planktonic and drift organisms when the summer ambient (24-27°C for most source waters) plus the ΔT results in a temperature of about 31°C. Another grouping of species can tolerate short-term exposures of up to 34°C, and still another group up to 35-36°C or more before they incur mortality.

The effect of the low (1-2°C) temperature rise above ambient in the far-field portion of the plumes is to stimulate metabolism and growth of aquatic life throughout the year in temperate regions where summer ambient temperatures do not usually exceed 26-27°C, and to exclude some cold water species from living space for a longer period of the year than would be the case if there were no thermal discharge. However, in sub-tropic and tropic regions, where organism's optimal range for growth tends to be closer to maximum summer ambient temperatures, such far-field plume temperature elevations may cause some inhibition of growth and changes in species composition of aquatic populations.

Chemical Stress

Various chemicals are discharged into the cooling water systems of steam electric plants. Most of the chemicals are not acutely toxic during the relatively short exposure times encountered during entrainment.

Chlorine has long been used in power plants to control biofouling because it is toxic to most aquatic organisms at relatively low concentrations, has been inexpensive, easy to apply, and was thought to decompose rapidly to non-toxic by-products. It is now recognized that some of the chlorine applied to condenser cooling water combines with ammonia and other nitrogenous materials to form chlorinated amines that are thought to persist much longer than free chlorine. Pump entrianed organisms are exposed to free chlorine during applications to the cooling system, and plume entrained organisms are exposed to any remaining free chlorine and chloramine residual.

Power plants located on fresh water bodies normally require chlorine applications infrequently so that chlorine may be applied during a small percentage of the total plant operating time. Much more frequent and in some cases continuous chlorination is often required at marine-sited plants to control fouling, especially by attached bivalves. Consequently, the potential for damage to entrained organisms is increased. Bio-fouling and frequency of chlorination required for control are normally greatest during maximum ambient temperature and reduced during cooler periods.

Formulation and adoption of minimal chlorination schedules and dosage rates necessary to achieve control at each site will eliminate unecessary damage to entrained organisms and reduce associated costs. The toxicity of chlorine to aquatic life is a function of exposure time, dose, chemical form of the chlorine and species specific differences in tolerance. Exposure time and dose are determined by the application protocol, and by volatization, decomposition and dilution rates subsequent to application.

The decomposition rate of free chlorine concentrations added to power plant cooling water can be expected to vary considerably depending on the "chlorine demand" (ammonia and organic concentration), temperature, pH, and chemical and photochemical reaction rates in the receiving waters. Almost nothing is known about the decomposition rates of combined forms of chlorine (principally chlorinated amines) although they are thought to be more persistent and pose greater chronic toxic potential than the free chlorine molecule.

The currently proposed EPA criteria for maximum acceptable residual chlorine concentrations are based on a conglomeration of data produced by a variety of experimental methods on waters of widely different quality, many of which were trout waters with low chlorine demands. Information on the decomposition rates and acute and chronic toxicity of free and combined chlorine in definitively characterized water quality types most used by power plants is urgently needed to provide bases for criteria relevant to local water quality characteristics.

Mechanical Stress

Entrained organisms experience stress resulting from mechanical buffeting, velocity shear forces, and changes in hydrostatic pressure. Abrupt changes in pressure occur at various points in the circulating water system. As water approaches the impeller of the intake pump there is a rapid drop in pressure which is immediately followed by a pressure increase on the back side of the impeller. The magnitude of the pressure differential experienced by entrained organisms depends on the depth from which they are withdrawn and the design of the intake pump impeller. The positive pressure* behind the intake pumps rapidly drops to as low as 2 psia in the condenser system. The reduction to negative pressure is concurrent with the temperature rise and occurs within 5 to 10 seconds during condenser passage. The maximum negative pressure is expected to occur at the condenser water box. As the flow enters the discharge system, there is a rapid return to positive pressure, the magnitude of which is dependent on the depth of the organism in the discharge system. Although relatively little work has been directed towards the effects of pressure changes encountered in power plants, it appears that negative pressures have the greater potential for damaging entrained organisms, especially fishes.

Mechanical buffeting and velocity shear exposure may be important factors in considering potential entrainment damage, especially with larger soft-bodied organisms. The magnitude of these forces is dependent on the physical characteristics of the cooling water system and the location of the organism in the flow. Both of these factors are difficult to measure in an operating power plant and even more difficult to simulate in laboratory situations. Therefore, little information is available concerning dose-response relationships.

Coal Pile Drainage and Ash Pond Overflow:

The characteristics of these wastes from coal burning plants differ greatly, because of such factors as differences in the chemical composition of coal, amount of rainfall, the initial quality of water used for ash handling, and design of settling ponds. Dissolved solids, suspended solids, a variety of trace metals, mineral acid (from coal piles) and sulfate in the wastes are potentially harmful to aquatic life. Synergism among a number of the metals may increase their toxicity. Harmful effects of iron, copper and zinc solutions can be greater in acid water produced by coal pile drainage than in neutral or alkaline water. The effects of these wastes on aquatic life in receiving waters are usually negligible but can be substantial in cases where the volume of the wastes is large relative to flow in receiving waters.

* The terms positive and negative pressure refer to increases and decreases in pressure, respectively, relative to the absolute pressure experienced by the organisms before being entrained.

Spillage of Coal and Oil

Spillage of coal and oil into surface waters during unloading operations is a threat to aquatic life. The oil and substances leached from coal are unsightly, can be toxic, and cause tainting of fish and shellfish that may render them unfit to eat. Oil is also a hazard to waterfowl. Excessive spillage of coal is damaging to most bottom dwelling organisms because they can not tolerate the abrasiveness of a shifting layer of coal. The effects of these factors on aquatic life is usually local, but may be severe in those localized areas. In the cases of several coal-fired plants we have studied, the only damage to aquatic populations in the receiving waters that we could detect was to the benthos caused by spilled coal and scouring by the prop wash of tug boats used to maneuver coal barges into and away from unloading morrages.

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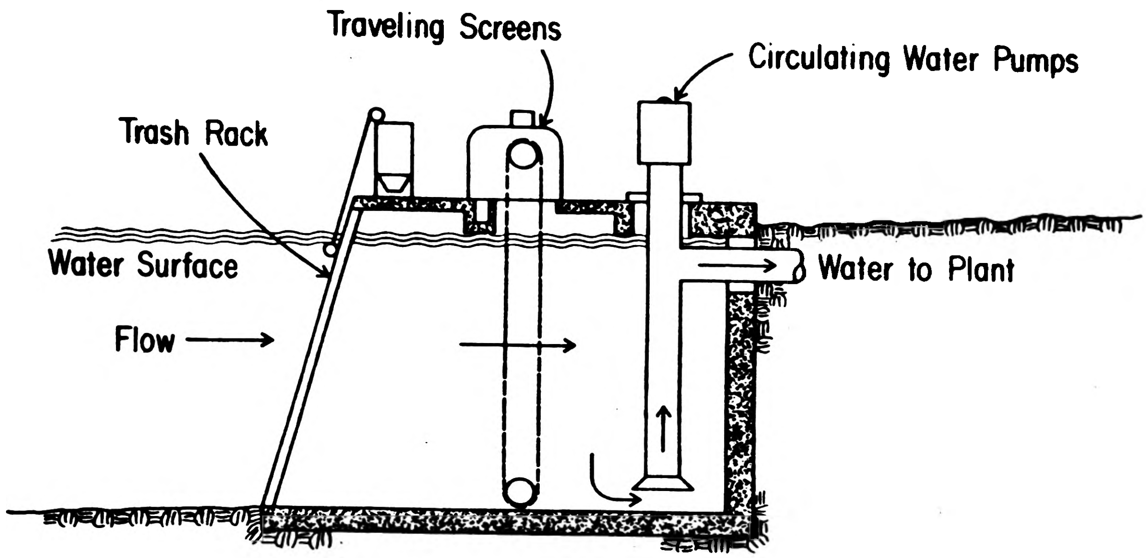

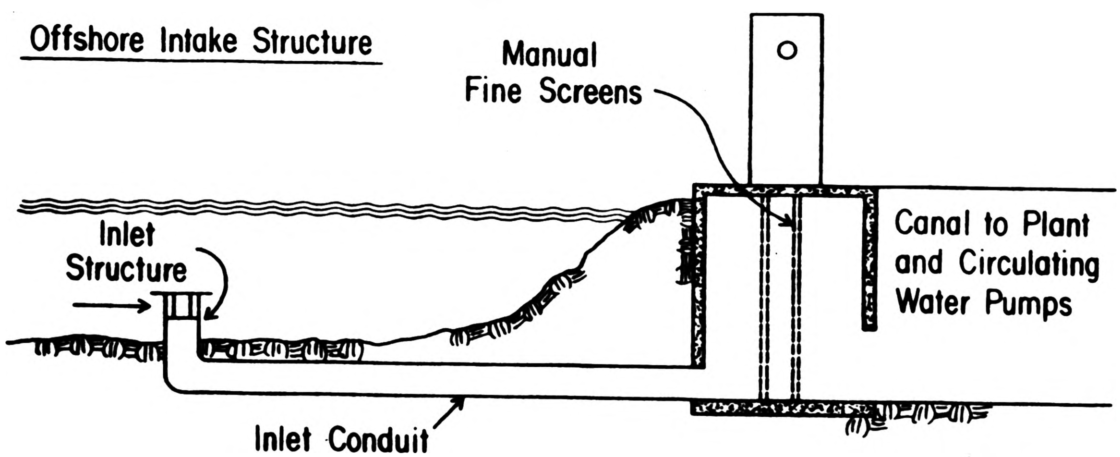

Figure 1. Schematic Diagrams of Typical Intake Structures (Point of Water Inlet to the Water Screening Facility)

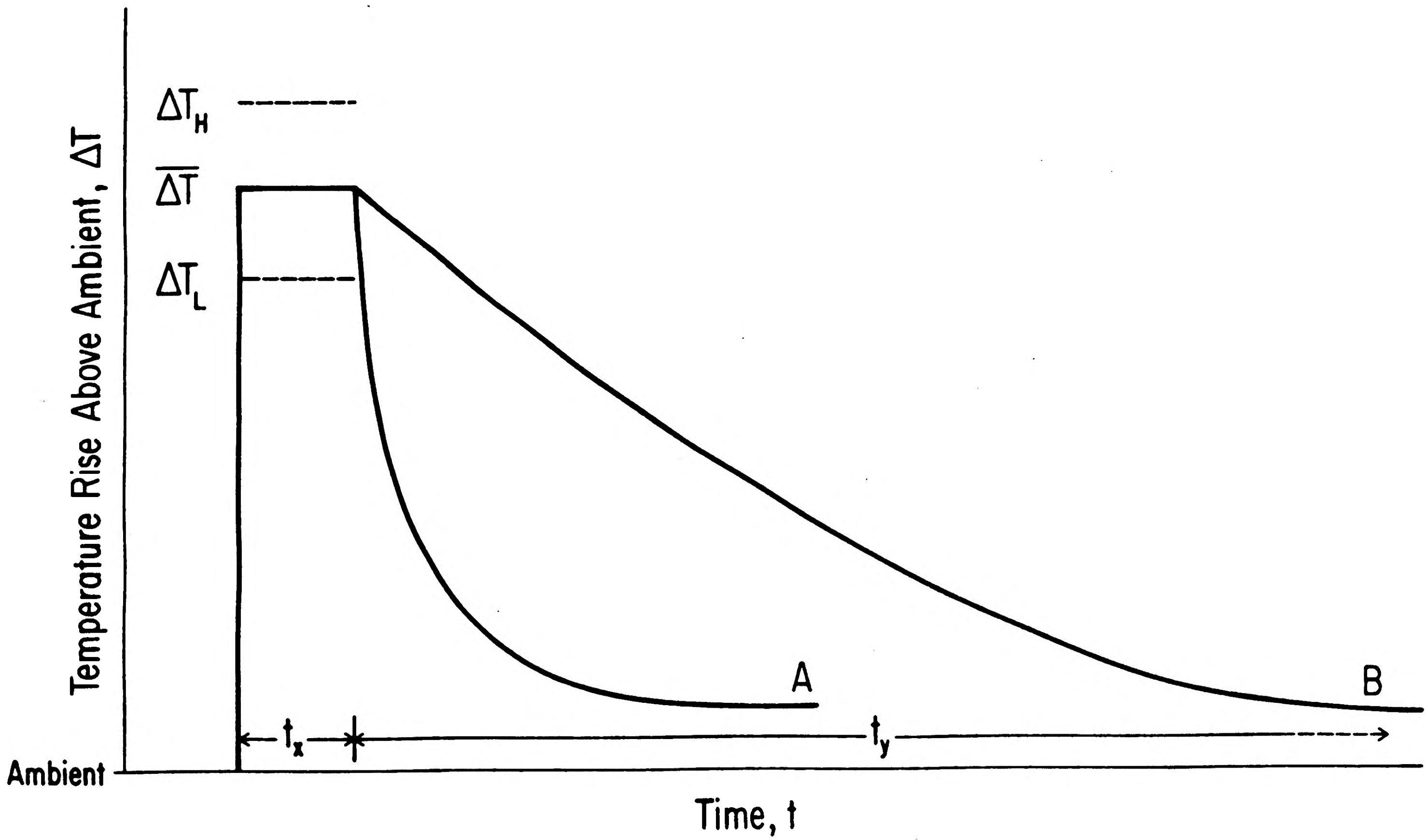

Figure 2. Generalized temperature exposure diagram for organisms entrained in a once-through, steam electric power plant cooling system. ΔT_L and ΔT_H represent the range and ΔT the average temperature increase experienced in the condenser. Inplant and post-discharge exposure times are represented by Tx and Ty, respectively. Curves A and B represent high and low rates of mixing, respectively.

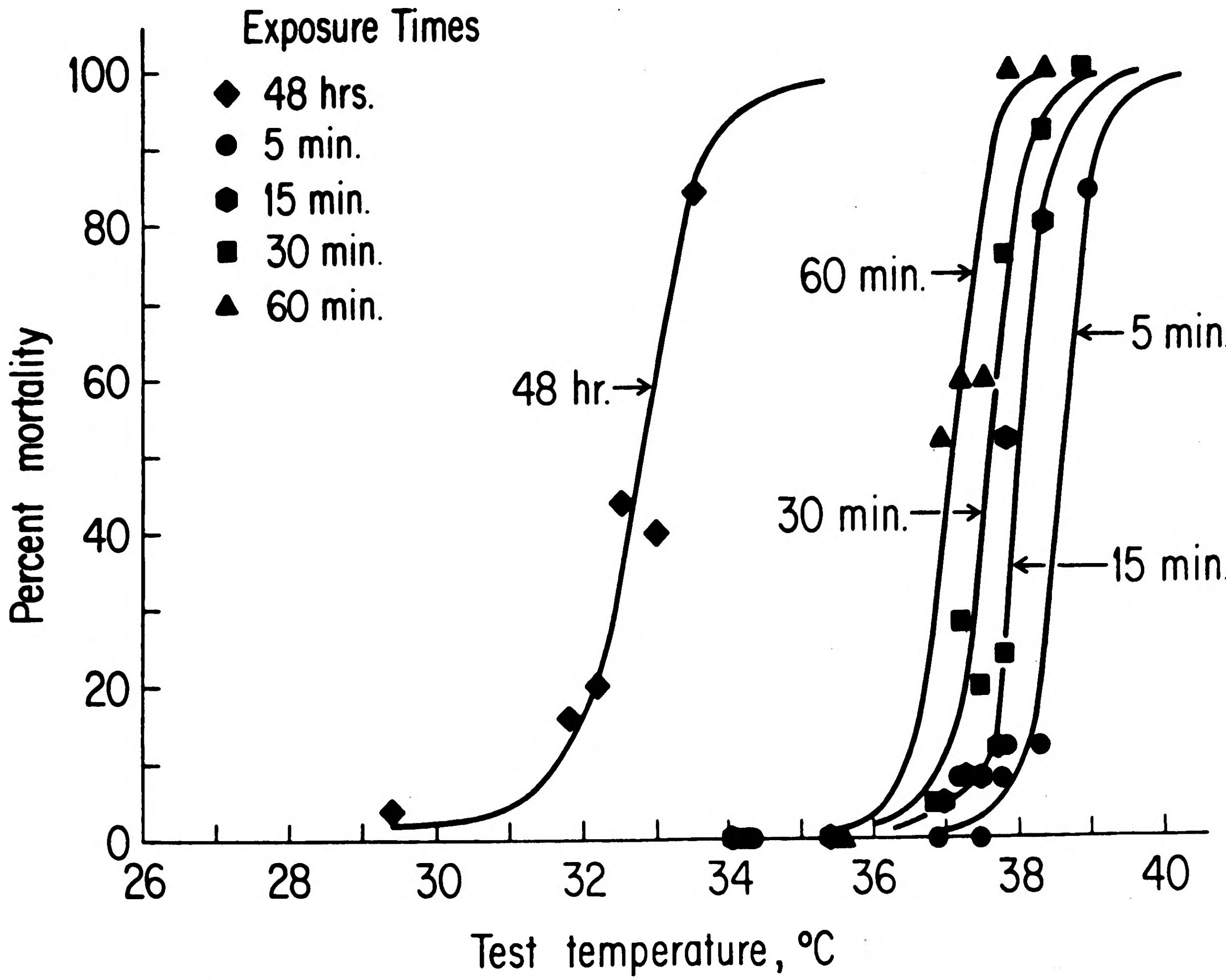

Figure 3. Temperature tolerance of Gammarus sp. at an ambient temperature of 24.7 to 25.8°C. (From Ginn et al, In Press)

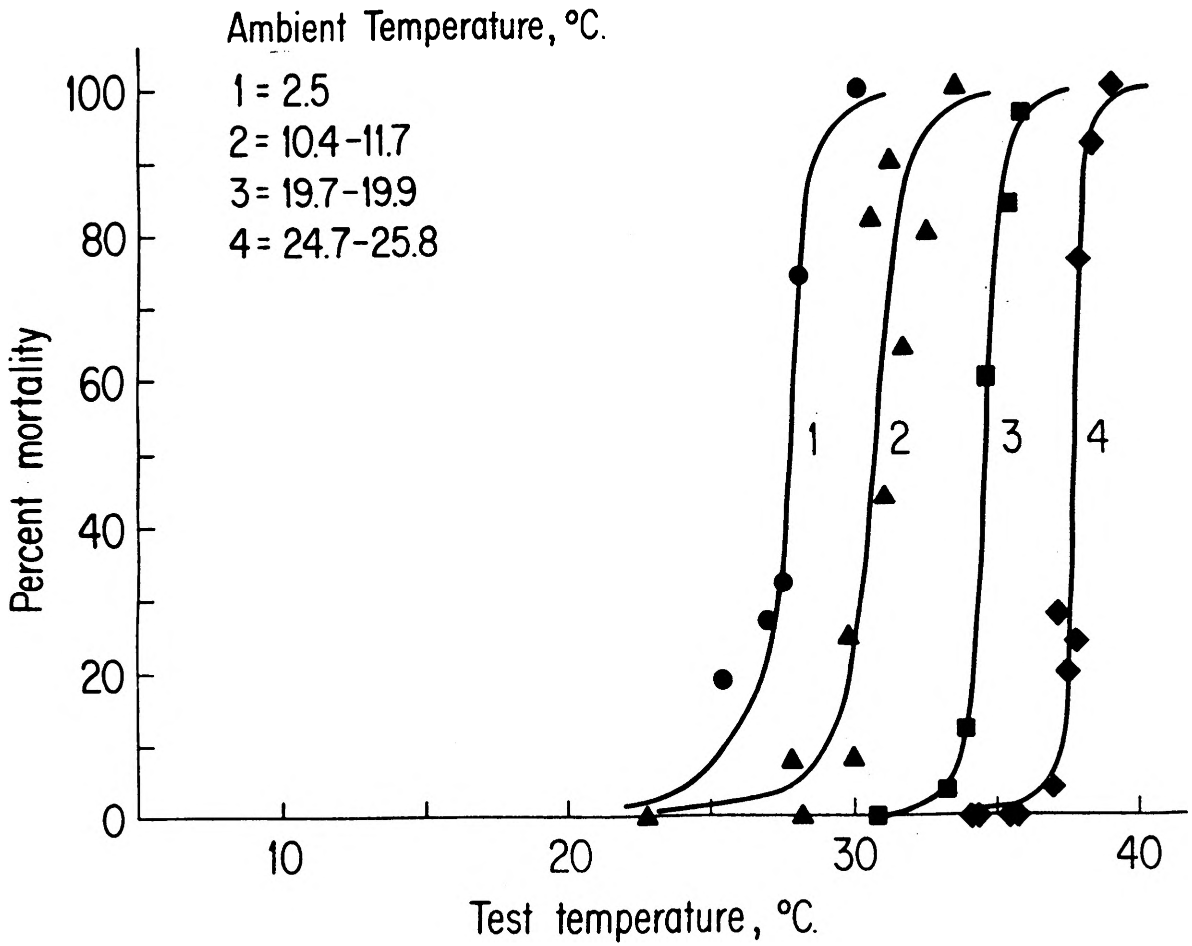

Figure 4. 30 minute temperature tolerance of <u>Gammarus</u> sp. (From Ginn et al, In Press).

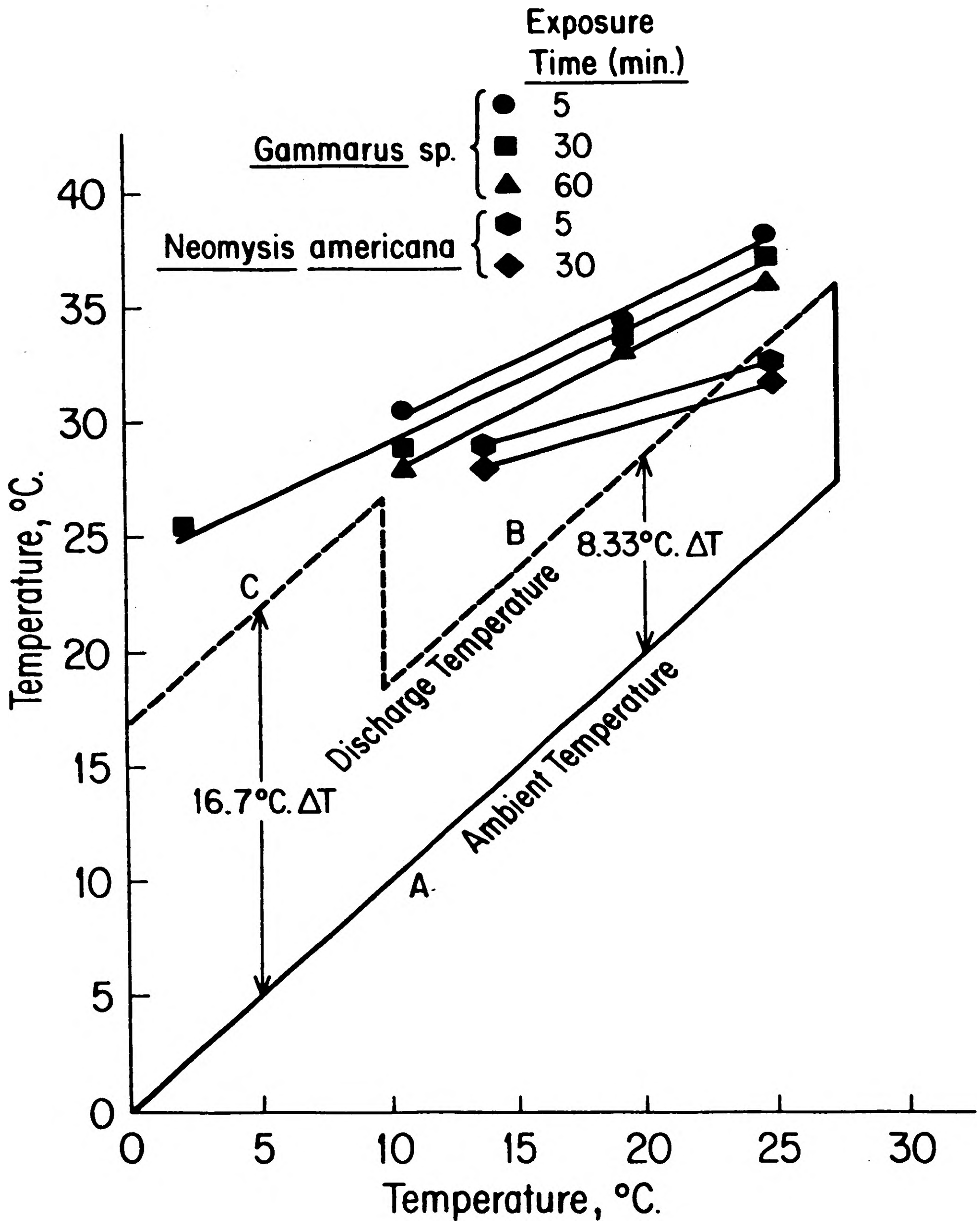

Figure 5. 95% tolerance limits for *Gammarus* sp. and *Neomysis americana*. Projected power plant ΔT's during full flow (line B) and reduced flow (line C) operations are superimposed over the ambient temperature range (line A).

AN ENVIRONMENTAL AND ENERGY INFORMATION SYSTEM*

G. U. Ulrikson G. M. Caton
M. P. Guthrie H. F. McDuffie

Oak Ridge National Laboratory
Oak Ridge, TN 37830

ABSTRACT

The Environmental Information System Office (EISO) at Oak Ridge National Laboratory (ORNL) provides information support for researchers and administrators involved with energy and environmental policy and progress. Multiple EISO activities for various governmental agencies have resulted in establishment of compatible data bases concerned with energy and environmental information, methods for effectively developing these, development and computer display of numerical data summaries, and reports evaluati pub- lished information. Direction is provided by continuing dialogue between users and information system staff.

INTRODUCTION

Our nation is striving to minimize environmental insults and potential hazards to human health while at the same time using advanced technologies for energy generation. Funding agencies, program managers, research administrators, and researchers need the best available information to make accurate, comprehensive decisions. Information analysis centers and systems organized to meet the needs of these groups can make valuable contributions to legislative decisions and research program direction.

To be relevant and effective, an information system must be designed for the user and must remain service-oriented throughout its existence. At Oak Ridge National Laboratory we have created an Environmental and Energy Information System which provides the information services listed in Table 1. These types of information have been determined after many man-years of effort. In the following sections we discuss these various services and how we fulfil them.

Table 1. Environmental and Energy Information Services

Bibliographic Information
Directory of Researchers and Institutions
Inventories of Current and Proposed Research
Factual Information Files
Numerical Data Files
Assessment of Information

BIBLIOGRAPHIC INFORMATION

In recent years the emphasis of energy and environmental research has changed from small disciplinary research projects in which researchers were aware of the current state-of-the-art of a given project. Today researchers of many disciplines, including engineering, physical, biological, and social sciences, are concerned with ecological, physical, chemical, and economic information in relation to the applied energy programs being developed.

Many available bibliographic services are oriented toward disciplinary objectives, e.g., *Chemical Abstracts*,[1] *Biological Abstracts*,[2] *Engineering Abstracts*,[3] *Physics Abstracts*,[4] *Metals Abstracts*,[5] and *Statistical Abstracts*.[6] In gathering bibliographic information for a given request or building an interdisciplinary information base such as energy, an information system can begin by using the large computer readable data bases produced by bibliographic services. The repackaging of this information rather than building new data bases is economical and expedient. If a proper search and retrieval strategy for each request is followed by the information specialist, much valuable information can be obtained

For collecting the maximum relevant information, we suggest the following plan (see Fig 1) The information specialist converses with the requester to get an understanding of specific needs of the user and then searches the available data bases for a reference list as a subset for that request. The number of references dropped for an interdisciplinary project varies according to the data bases searched and the keywording of those data bases. The list of journals from this bibliographic search provides the information specialist with a list of "core" journals in which authors are publishing relevant material The most recent of these journals are often manually searched The authors cited in this search can become an "expert" directory data base. By using *Science Citation Index*,[7] one can find who cited the paper listed in the original search and how many times, the authors' listing in this index journal provides a comprehensive bibliographic service. With this listing a specific project-oriented bibliographic data base can be constructed with individual subfiles Documents can be purchased for users, special libraries constructed, bibliographies produced,[9-12] and specific searches accomplished

An example of an interdisciplinary service is *NSF-RANN Energy Abstracts*,[8] a monthly journal which the Environmental Information System Office (EISO) of Oak Ridge National Laboratory (ORNL) began publishing in January 1973 Its primary purpose is to disseminate as rapidly and widely as possible the published results of research on energy. Each citation contains the title, author, corporate author and address, sponsor, publication description and date, abstract, availability, and price. Indexes by author, corporate author, keywords, and permuted words of the title are issued semiannually. Beginning with the January 1974 issue, the citations in each issue are grouped by subject category to facilitate rapid scanning of fields of interest.

The subject coverage of *NSF-RANN Energy Abstracts* includes energy and electric power h and development, conservation, supply and demand, economics, and environmental effects, all energy sources, including unconventional sources such as solar, tidal, and waste products; electric power generation and transmission, energy storage; and energy demand and consumption, including all consuming sectors.

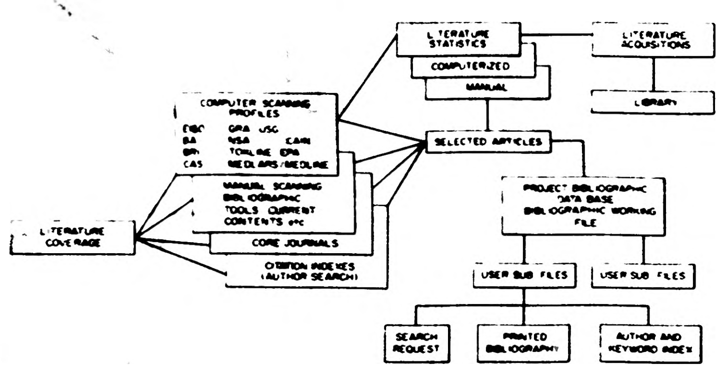

Fig 1 Search and retrieval strategy of bibliographic information.

DIRECTORY OF RESEARCHERS AND INSTITUTIONS

A second important need of researchers is a directory of people and places involved in pertinent areas of research. The EISO computerized directory lists approximately 20,000 persons by name, address, telephone number, and various types of identifying labels and keywords. This directory is used to maintain distribution lists and to locate researchers and administrators More specialized subsets can be prepared and used to maintain and publish directories for

*Work supported by the U.S. Atomic Energy Commission under contract with the Union Carbide Corporation.

specific programs such as the *NSF-RANN Trace Contaminants Directory*[13] Once these data bases are constructed, they can be used for searching geographic locations by zip code or area telephone number and experts by professional or research interest

INVENTORIES OF CURRENT AND PROPOSED RESEARCH

Comprehensive data files listing current research projects in detail can be prepared An example of this is the *Inventory of Current Energy Research and Development*,[14] which is a compilation of 4,907 descriptions of energy-related research and development projects conducted or sponsored in the U S since 1971 It is an expanded and updated version of the March 1972 *Inventory of Energy Research*[15]

The scope of research projects for the current inventory is broad, including. (1) all types of energy sources — fossil fuels, nuclear, hydroelectric, solar, geothermal, tidal, wind, wood, plant, animal materials, and waste products, (2) electric power — generation, transmission, distribution, and storage, (3) energy uses — residential, commercial, industrial, transportation, agricultural, and specialized applications, and (4) health and ecological effects Subcategories under appropriate headings include exploration, mining, processing, resources and reserves studies, information on any basic or applied research, engineering development, economics, environmental effects, policy, regulatory, and legislative studies relevant to the above subjects

The description of each research project lists, if available, the following information the title of the project, the research institution and address, the investigator(s), the funding organization, the duration of the project, the amount of funding by years, a brief summary of the research together with a list of pertinent publications, and the state in which the research is performed (Fig 2) Several summary tables of funding and a number of indexes are also provided One table gives the total funds provided by each type of sponsor for each subject category, a second gives for each state the number of projects and the total funding, a third gives the total funds allocated to different types of research facility, the fourth table gives the total number of projects and total funds for each subject category Five indexes are given on research facility, sponsor, investigator, location of research, and permuted words of the title This information is stored in a computer file which permits easy updating and rearranging of the information Selected subsets of the energy file can be obtained

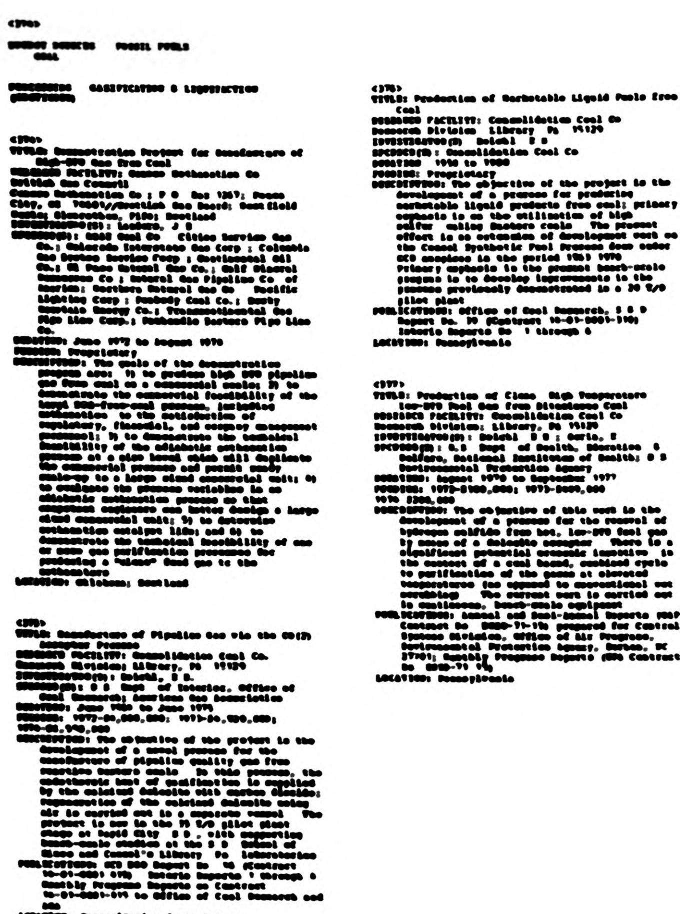

Fig 2 Example of research project information.

Another of our computerized and subsequently published files is the *NSF RANN Trace Contaminants Abstracts*,[16] a bimonthly abstract journal in which research results are reported by the grantees in the NSF RANN Trace Contaminants Program The abstracts are accompanied by an informal newsletter containing brief program notes This abstract journal facilitates the exchange of information among the grantees and others interested in this area of environmental concern

Other examples of information bases containing such information include *Office of Coal Research Annual Report 1972*,[17] *CRC Air Pollution Research Advisory Committee Status Report*,[18] *Survey of Research — Projects Reported by Electric Utility Systems in the United States*,[19] *and Abstracts of FY 1973 RANN Awards — Energy Research and Technology*[20]

FACTUAL INFORMATION FILES

In addition to building comprehensive bibliographic files, it is becoming important for information centers to answer questions For example, factual information about a chemical substance released from energy generating stations and processes is necessary in order to assess the effects of that chemical on the environment Many factual information files exist today, however, many of these have been produced with a single objective There are desk top reference books such as the Chemical Rubber Publishing Company's *Handbook of Chemistry and Physics*[21] for chemical and physical data and *Biology Data Book*[22] for biological data Another published work of this type is the Public Health Service Publication 149, Volumes I — V,[23] on carcinogenicity of chemicals

The necessity for establishing data files, particularly in the area of toxic materials, has been recognized by such groups as the United Nations Advisory Committee on the Application of Science and Technology to Development, the Scientific Committee on Problems of the Environment of the International Council of Scientific Unions, and the United Nations Conference on the Human Environment

The Environmental Information System Office of ORNL is demonstrating the feasibility of factual data systems and is using the efforts of its individual information center units to construct various interlocking data files that show promise of conversion to a large integrated file For example, the Environmental Mutagen Information Center (EMIC) could extract and publish data concerning the potential mutagenicity and teratogenicity of compounds encountered in the mining and refining of fossil fuels

The Biomedical Sciences Section (BMS) of EISO is extracting toxicologically related information for the Toxicology Information Program of National Library of Medicine This information could be used to discern real and potential biologic effects resulting from energy generation

The Toxic Materials Information Center (TMIC) is determining the feasibility of reducing scientific and technical data pertaining to the sources, transport, and fate of trace contaminants in the environment These data would be machine-stored in their reduced form and could be printed out in tabular form

The combination of these specialized files makes a comprehensive data file from which valuable information could be gleaned, such as the impact of energy-related chemicals or substances in the environment In providing information to users, quick and easy access to the computer file and also the versatility of searching on various "fields" or "subject headings" are important

NUMERICAL DATA FILES

The last type of information capability, needed mainly by researchers but also by decision makers is numerical data bases With the growing concern for better land use planning new energy sources, environmental impact of power plant construction, economic growth and development, and man-made changes in our environment, there is a need for detailed numerical data that can be merged with all other types of information for final assessment.

Information system scientists can play a major role by knowing where files are located, the content of the data files, the means of accessing the data, and the shortcomings and strong points of the data in relation to the needs of the requester. Information scientists can work closely with the people they serve to minimize the lag between a perceived need for information and the actual delivery of that information.

We commonly use several types of numerical bases in support of impact and assessment studies at ORNL. Examples of these are 1970 U.S. Census Data and Statistical Abstracts produced by U.S. Department of Commerce, Bureau of Census; Current Fisheries Statistics, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, produced in cooperation with the states; Earth Resources Technology Satellite Data, NASA; and water quality and flow data, U.S. Geological Survey.

Information systems can now locate and subset these data for specific problems. ORNL routinely uses the census data for electrical power plant impact analysis. We hope that in the future there may be a common system in which environmental numerical data bases can be accessed according to regions of specific interest.

ASSESSMENT OF INFORMATION

The information gathered in the files just described is often passed on to the requester for evaluation. However, information systems can play a significant role in the evaluation of data and the subsequent preparation of reviews and state-of-the-art documents. Senior information scientists with academic specialties in the area under review can unify the efforts of the more generally oriented information center staff with those of the highly specialized research participants or university professors to produce extremely useful and accurate state-of-the-art documents.

CONCLUSIONS

An example of information system support for researchers and administrators involved with energy and environmental policy and progress, EISO is necessarily service-oriented to user needs. Multiple EISO activities for varied government agencies have resulted in the establishment of compatible data bases concerned with energy and environmental information. The establishment of data bases, methods for effectively developing and exploiting them, development and computer display of numerical data summaries, and reports evaluating published information are actively being pursued. Direction is provided by continuing dialogue between users and information system staff.

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VIII - INDUSTRIAL ENERGY MANAGEMENT

Co-Chairmen:

G. R. Cuthbertson and B. R. Sarchet

FUTURE UNITED STATES ENERGY DEMAND PATTERNS

by

Leland Blank
Assistant Professor
Industrial Engineering
University of Texas - El Paso

Richard Riley
Assistant Professor
Mechanical Engineering
University of Missouri - Rolla

ABSTRACT

The future energy demands of the United States are forecast using a unique approach. The saturation forecasting method reflects the inability of an individual to utilize more than a limited amount of energy. This technique also allows evaluation of various conservation methods and their effects on the future energy needs.

OVERVIEW OF ENERGY USE AND DEMAND

We in the United States use extremely large quantities of energy each year; in 1970 a total of 67.8 quadrillion (67.8Q) BTU were used. An idea of how much energy this represents may be obtained by comparing the energy needed to boil a certain quantity of water. One Q of energy is necessary to boil away the amount of water in an area of one square mile covered with 515 feet of water.

The present method of obtaining most of the energy is the burning of various fossil fuels: coal, natural gas, and liquid hydrocarbons. These fuels are available in some limited quantity and their formation rates are much less than present usage rates. As the supply of these traditional fuels decreases, their value, as both a fuel and a raw material, increases. Thus, these sources must be consumed at a decreased rate or alternate energy forms must be discovered.

In this paper, emphasis has been placed on minimizing the use of energy, while meeting reasonable demands of our society. Due to the many and complex uses of energy, a careful study is made of the several different areas of the entire energy picture. The demand for energy involves a study of the forms of work and a forecast of the quantities required for each form.

Considerable historical data is available concerning energy usage; additionally, other studies indicate the amounts of available supplies and their condition. Future energy demands have been predicted in several studies [1 through 17]. Methods used in these projections have various bases, some being: population growth, trending of historical data, gross national product, regression techniques, energy use per capita, and questionnaires, opinions, and judgement.

The growth of demand energy has been based on the increased production capacity of the United States. To maintain its place in the world, this country has developed many new processes to produce conveniences for its people not thought to be necessary by earlier citizens. As a result, energy demand has grown very rapidly as shown by the doubling times for energy use in Table I.

TABLE I. DOUBLING TIMES FOR ENERGY USE

Year	Annual Use (10^{15} Btu)	Doubling Time (Years)
1910	17.0	--
1948	34.0	38
1970	68.0	22
2000(est)	136.0	30

Many of the resulting projections of demand follow a historically established exponential curve into the future. This method is popular not only in demand forecasting, but has been used in other areas where exponential growth is historically true. An example is the study performed by a research group at MIT, the results of which are published in the book "The Limits to Growth" [18]. However, this analysis for future demands for energy does not support the exponential growth projection. The forecasting of demand in this paper does not follow any of the previously mentioned methods per se, rather it utilizes a method of <u>saturation forecasting</u> applicable to most areas of energy use.

The saturation concept reflects the inability of an individual person or household to utilize more than a certain amount of energy due to time and spatial constraints. The time restraint implies that each person has within each day a number of activities, each having the use of energy connected with it. Although this individual has the option to select among the activities, only a few may be engaged in at one time. Each individual has a limited amount of space, which is necessary and sufficient for a selected activity. Thus, an individual can engage in an activity only as limited by space and time, only a limited amount of energy can be expended. By forecasting the time and space required for activities, maximum energy usage per capita (saturation) may be established.

Conservation efforts are detailed to obtain what are reasonable appearing projections when factors of environment, scarcity of energy sources, and costs are considered.

The total energy demand forecasts were obtained by the 'building block' or composition forecasting method. This required the forecasting of saturation and conservation demand for the different individual use areas. The projections were then combined to obtain forecasts of the common user areas, these being:

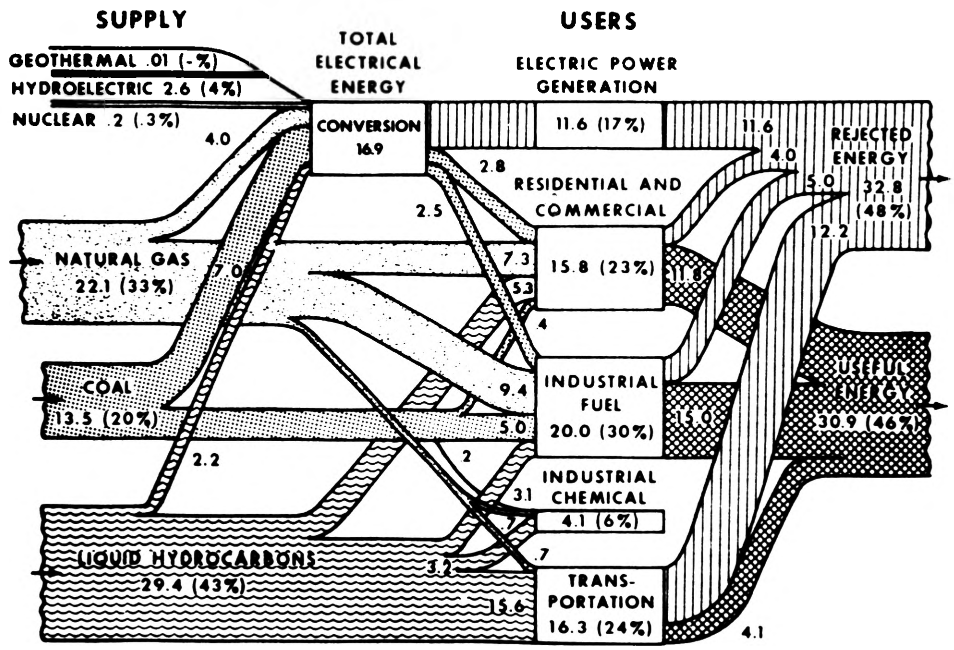
residential and commercial
industrial - fuel
transportation
electric power generation
industrial - chemical

The complexity of the U. S. energy use patterns of 1970 is depicted in Figure 1 [14]. The future demand pictures for total energy are presented in Figure 2 (saturation) and Figure 3 (conservation). Details of the logic behind these curves are given in the ensuing sections.

FUTURE DEMANDS

Residential and Commercial

The residential uses of energy are concentrated in houses, mobile homes and apartments. In 1970, there were 64.8 million households in the U. S. This is expected to increase to 90 million (39% increase) by the year 2000. The commercial area encompasses energy requirements of the facilities utilized by business, but not for the production of producer of consumer goods. Typical facilities are retail, whole-



(ALL VALUES ARE × 10^{15} BTU - TOTAL U.S. DEMAND 67.8 × 10^{15} BTU)

Figure 1. U. S. Energy Demand Patterns, 1970

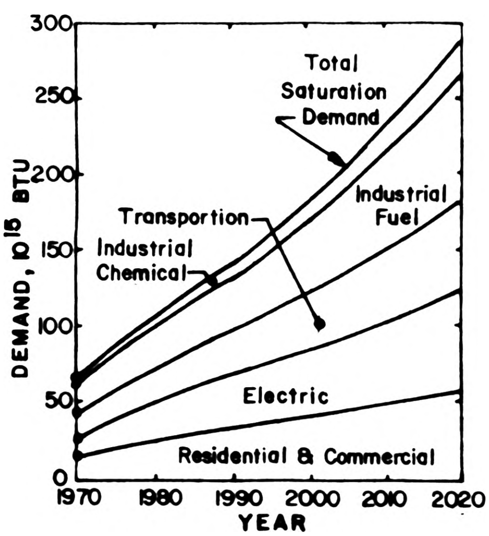


Figure 2.
Total Saturation Demand by Area, 1970-2020

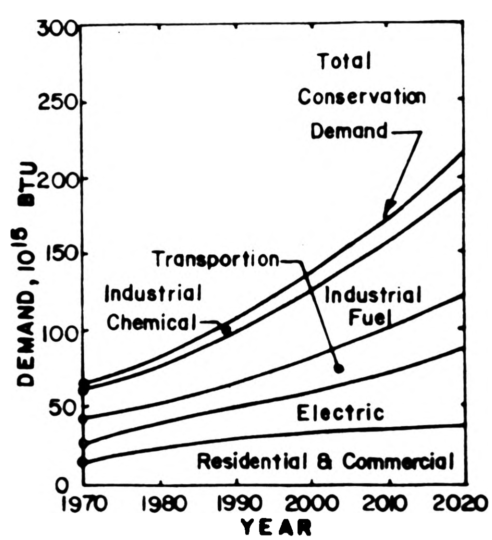


Figure 3.
Total Conservation Demand by Area, 1970-2020

sale and sales organizations, hotels, and office space occupied by service and industrial groups.

Eighty-eight percent of the total residential and 77% of total commercial energy is expended on space conditioning (heating and air conditioning), water heating, cooking, and refrigeration [15]. Residential energy needs are supplied by electricity (15%) and fossil fuels (85%). Commercial, representing approximately 15% of total area energy demand, derives 65% of its energy from fossil fuels and 35% from electricity. The last decade has seen particularly large increases in air conditioning and other comfort items. Historical consumption growth rates have been 2.7% for residential and 3.7% for commercial [4].

A summary of the 1970 household energy consumption and device ownership is shown in Table II. This table also provides the starting point to define saturation in this area. As facilities necessary to provide comfortable surroundings of adequate space are completely installed in a home, some limit is reached. This limit interpreted as a saturation demand for the individual household, was obtained by assuming that each household was adequately heated, completely air conditioned, and supplied with heated water, refrigeration, adequate lighting, and a number of convenience appliances. This will place each household at a demand of about 400 million BTU's annually.

TABLE II. PATTERNS OF 1970 HOUSEHOLD APPLIANCE OWNERSHIP AND ENERGY USAGE

Household Item	No. of Households with Item (millions of Households)	Percent of Households	Energy Use (million BTU per Household Year)
Space Heating	64.8	100.0	110.0
Air Conditioning (Room)	26.0	40.6	
Air Conditioning (Central)	8.9	13.7	7.0
Water Heating	35.7	80.5	28.5
Cooking	64.8	100.0	10.5
Clothes Dryer	34.7	53.5	3.4
Refrigeration	63.9	100.0	11.4
Other			20.4
Total			191.2

Commercial uses of energy do not fit an exact definition of saturation but the growth in this area is affected by the population growth and the proliferation of the services provided to the public. These two factors will cause growth in the commercial area of about 3.5% annually until population growth is reduced. Figure 4 represents the saturation demand for both residential and commercial areas.

Conservation will be seen in this area due to shortages and pricing changes of fuel. The conservation curve of Figure 4 reflects major conservation in both residential and commercial by the use of better insulation and design techniques which can reduce the thermal losses of a structure by 50% [15]. This will eventually produce a 25% savings of energy in residential and 30% in commercial. Unfortunately, full effect of this is long term since its application is only to new construction.

Besides the above, a 6% savings of the anticipated 1985 household load of 400 million BTU per year will be due to increased device efficiency in lighting, water heaters, ranges, refrigeration, and air conditioners.

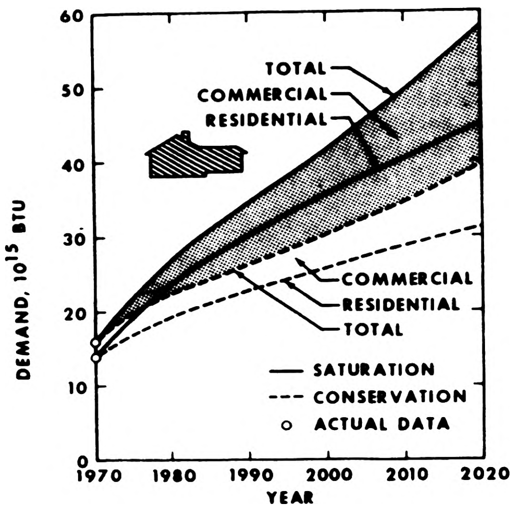


Figure 4.
Residential and Commercial Demand, 1970-2020

Transportation

The transportation area encompasses the energy in all fuels consumed to provide motive power for passenger and freight movement. This area, the most visible of all energy users, consumes 24% of total energy. A variety of modes, all fossil fuel based, are prevalent, but all may be compressed into four general groups. These are private automobile travel, 55%; freight carrier, 27%, including highway, rail and water systems; commercial passenger, 8%; other, 10%, including off road uses and pleasure crafts. Each is given with its share of energy consumption.

The 4.1% yearly growth rate [19] of the recent past has occurred primarily due to increases in truck, automobile, and aircraft traffic. This, of course, is readily seen from the proliferation of highway and airport construction, which encourages a decentralized style of living, working and recreation. The demand for transportation energy will continue to grow, but a decline in the growth rate is anticipated. Saturation demand is defined by a limit in private automobile travel. Presently automotive travel represents a considerable amount of time in each person's day (approximately one hour). However, there is some reasonable limit on the time available for travel when other personal activities are accounted for. The movement of freight and commercial passenger travel are expected to grow at a rate paralleling industrial growth of 3% per year. Projected demand for transportation with the above saturations is pictured in Figure 5.

Conservation efforts to reduce total miles traveled can reasonably be expected to occur in the transportation area as the energy shortage and rising fuel costs become more dominant factors. A total of 35% of the private automobile travel is work oriented [15]. An immediately available conservation effort is the use of car pools for this travel, which can affect about 20% of the transportation energy use and could result in a 10% savings. A more realistic view of work oriented traffic would expect 30% of the travel by one person in a car, 40% in multiple occupancy autos and

40% by some form of mass transit. This would cause an 11% fuel savings by 1990. Again, a change in the private automobile, which can be anticipated by 1985, is extensive use of the more economically sized vehicle. These effects on fuel consumption would amount to a 33% savings for auto use. Nearly two-thirds of car use is independent of employment travel, these activities include family business, entertainment, visits, and vacations. As economic pressure is exerted, anticipated changes include both declined use and a shift to less energy intensive modes of travel.

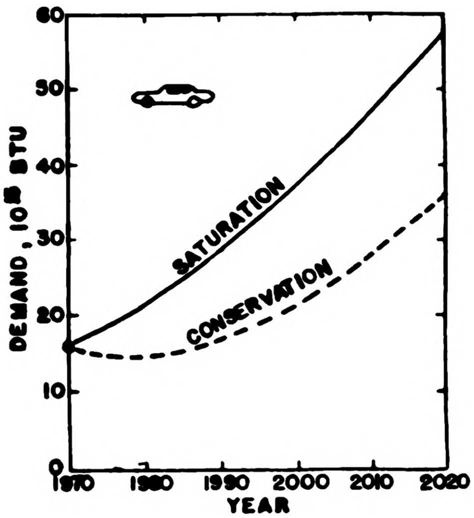


Figure 5.
Transportation Demand, 1970-2020

Table III shows some of the expected changes in the patterns of use for various purposes. Commercial freight traffic consumes a sizeable portion of the energy used in transportation (27%). As fuel costs rise and highway traffic increases, some shift in the mode of freight shipment is anticipated. Shifts to modes requiring less energy as well as reduction of multiple trip shipment of the same material is anticipated to reduce the truck energy consumption by 50%. The cumulative effect of these conservation efforts on transportation energy use is shown in Figure 5.

TABLE III. PRESENT AND EXPECTED NON-WORK ORIENTED AUTOMOBILE TRAVEL

Travel Purpose	1970 Mileage (%)	1980 Savings (%)	Transfer to Commercial (%)
Family Business	24.6	15.0	4.0
Entertainment	18.6	10.0	2.0
Visiting	12.2	10.0	3.0
Business Related	8.0	6.0	---
Vacation	2.5	1.5	0.5

Industrial-Fuel

The consumption of energy in the processing of materials is currently the largest single area of energy use (30%); including the use of electrical power and fossil fuels. Some of the principal sectors of industrial-fuel use are (percentage in parenthesis represents its 1968 share of area energy use)[19]: primary metal industry (21%); chemicals and associated products (20%); and petroleum refining and related industrial (11%). The energy demands of the industrial-fuel area are supplied by a variety of fuel sources; natural gas (47%), coal (25%), liquid hydrocarbons (16%), and electricity (12%). Historically all sectors have shown a decrease in the energy used per unit output. This trend has been altered recently due to environmental restrictions and the greater effort needed to obtain raw materials as supplies become increasingly scarce and more remote. The past increases in efficiency (due to new processes, automation and recycling), largely responsible for decreases in energy per unit output [14] are expected to return to overtake the present short term trend of increased energy per unit output. Growth in industrial-fuel has been 3% per year in the past and is expected to continue at this rate for future demand, thus displaying no real saturation, however, saturation has an effect due to the personal traits of the consumer. This continuation is anticipated due to the need for new products, population growth and necessary replacement of presently owned goods. The projected demand is shown in Figure 6.

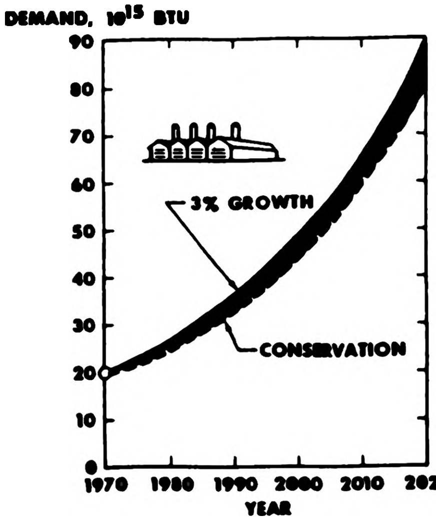


Figure 6.
Industrial-Fuel Demand, 1970-2020

Future conservation is anticipated in this area as energy economics are changed. The most likely areas are: more efficient equipment and processes; better maintenance policies; replacement of old equipment; and more conscious use of energy.

These measures could save as much as 20% of energy used as industrial-fuel, if very severe economic pressure were present. But, it is most likely to only produce a 10% savings.

Industrial-Chemical

The industrial-chemical area has no true demand for energy, but uses fossil type materials as raw materials in the production of goods. Thus the demand curve will represent the equivalent energy contained in these end products, some examples being: ammonia, plastics and resin materials, synthetic rubber, lubricating oils, and a diversity of other products.

Growth in the industrial-chemical area has been 6% per year in the recent past. This rapid growth has resulted from the many new products derived from fossil materials and a growing demand for these products. The demand for products derived from the traditional fuels used as raw materials can be expected to increase as the use of fertilizers and convenience consumer goods increases. The anticipated growth rate, however, will decrease from the present 6% per year to 3% in 1985 due to limits in the amount of these goods which can be beneficially utilized. The saturation curve of Figure 7 reflects this decreasing growth. A more conservative projection results when consideration is made of a fossil material shortage and the effects of these synthetic products on the environment. Under these conditions the growth rate is expected to decrease to 2.5%.

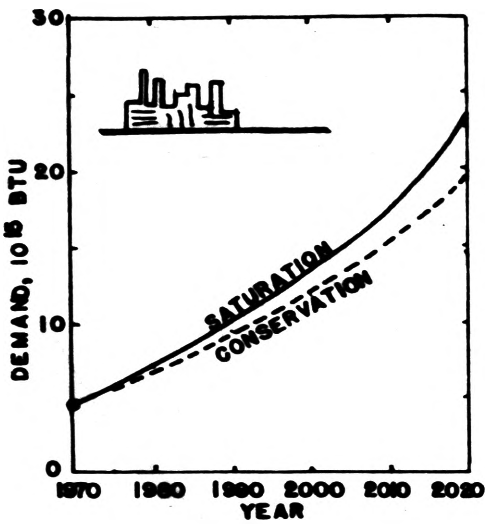


Figure 7.
Industrial-Chemical Demand, 1970-2020

Electric Power Generation

In as much as the useful output of the electric generation industry has already been accounted for in other use areas, this area is defined as the energy which shows up as rejected heat from total energy for electric generation and distribution. This is approximately 69% of the input energy for generation and distribution.

Electric power generating energy is obtained from various sources: coal (46.5%), natural gas (23.5%), hydropower (15%), liquid hydrocarbons (13%), nuclear and other (2%). Environmental and scarcity factors are a pressing reminder that other forms of fuel must in the future represent a much larger portion of the energy sources.

The demand for electrical energy in the user area has grown rapidly in the past (7% per year) due to the convenience and active promotion of this form of energy. Since the user determines the energy need in electrical power generation, the respective area demands define the future needs for this area. Of the present residential energy, 16% is supplied by electricity. This is expected to increase to 30% by 1985 and to 35% by 2020, due to the increasing use of electrical devices in the residential area. The commercial area use of electricity is anticipated to grow at the commercial growth rate of 3.5% per year and industrial-fuel usage is to continue at an established rate of 3% annually. Summation of these three projections yield a saturation curve presented in Figure 8.

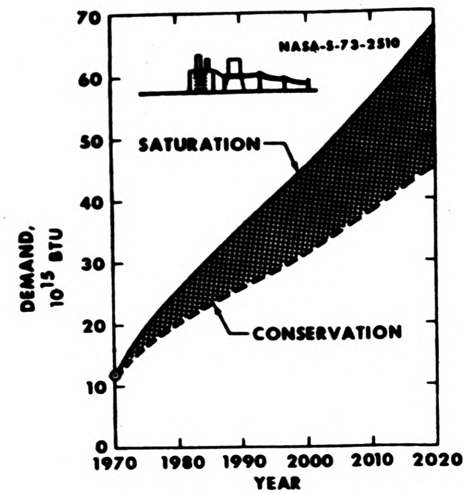


Figure 8.
Electric Power Generation Demand, 1970-2020

Future conservation in the area will be possibly dependent upon conservation in the user areas. More conscious use of electricity by the consumer will definitely cause decreased use in electric generation. The conservation curve of Figure 8 allows that 50% of the savings due to residential and commercial area conservation will be reflected in this area. The industrial-fuel savings of 10% are transferred to a like savings in electric power generation. In 1985, approximately 25% of the generation demand can be conserved by these measures. Energy demands in this area are of course modified by any efficiency changes in generation, but only small overall changes are anticipated. Overall conservation of energy is possible by the use of heat rejected from the generation process for heating; however, this possibility is not reflected in the demand of Figure 8.

Conclusion

A view of the forecast of the United States energy demands indicates substantial increases in the following few years. A realistic view would indicate that significant energy conservation measures will become a necessity. As fuel scarcity becomes a larger factor and a thrust to become energy self-sufficient is implemented, more awareness of energy dependence will force the country into different energy use patterns. It should be recognized that predictions for saturation (Figure 2) and conservation demand (Figure 3) are bounds within which the real use will fall, not expected real values.

As with any forecast, the accuracy can only be assessed with the passage of time, but trends may be noted much earlier. This forecast was made in the summer of 1973 and already several items predicted have began to show in the United States patterns of life.

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AN ADVANCED SUPERVISORY INDICATION, CONTROL & DATA ACQUISITION SYSTEM

George W. Fox
Union Electric Company
St. Louis, Missouri

ABSTRACT

Electric Utility systems in the United States double in growth every ten years. This growth necessitates the construction of substations in new areas and expansion of substations in existing areas.

Troubles quite often cannot be quickly and accurately diagnosed until a sufficient number of calls have been received from customers to establish a pattern.

This paper will describe an advanced supervisory system utilizing latest state-of-the-art electronic equipment interfaced with digital computers to provide the trouble dispatcher with a rapid update as to the status of his system at all times. He will also be able to remotely control his system as well as receive essential operating data.

INTRODUCTION

Union Electric is an investor-owned utility with corporate headquarters located in St. Louis, Missouri. It serves over 700,000 industrial, commercial and residential customers in the states of Missouri, Illinois and Iowa; an area of some 19,000 square miles. In addition, Union Electric provides gas service to 43,000 customers in the Alton, Illinois area as well as steam heating to over 600 businesses in the downtown St. Louis area.

Union Electric's 1973 net integrated system peak was in excess of 5,000 megawatts. Its generation facilities consist of fossil fuel steam plants, combustion turbines, run-of-the-river hydro, conventional hydro and pumped storage hydro for a total nameplate capacity of 6,097 megawatts. 1200 megawatts is planned for in service in the near future at the new Rush Island Plant, presently under construction 30 miles south of St. Louis and a 1100 megawatt nuclear plant located near Fulton, Missouri is planned for an in-service date of 1981.

It became apparent by the mid-sixties that some means of rapidly and accurately alerting the distribution dispatchers to 4 and 12 kV feeder lockouts in the St. Louis City and adjacent areas was vital for improved service restoration. For example, on June 28, 1969, a severe storm disrupted service to some 17% of our customers in the metropolitan area; about 50 distribution feeders were locked-out.

In the fall of 1970, Union Electric's management initiated a formal study and throughout the following year, manufacturers of supervisory equipment were contacted to gather information that would ultimately lead to a bid specification. It was decided that this specification would be conceptual in nature in order to take advantage of the latest state-of-the-art developments in the supervisory field. Bids from a carefully selected list of manufacturers were requested in March, 1972 and in June of that same year, after an in-depth technical evaluation, the contract was awarded to Control Data Corporation of Minneapolis, Minnesota.

It is significant to point out that this system is the first major one of its kind anywhere in terms of magnitude, both initial and ultimate. The initial contract calls for 196 remote terminals with an ultimate of 300 terminals within the next 10 years. These remote terminals are located throughout St. Louis City and County as well as the regional areas of E. St. Louis, Alton, St. Charles, Jefferson and Franklin counties.

SYSTEM CONFIGURATION

The master station, which will be located in the Company's Distribution Dispatching Office in St. Louis, consists of two SC-1700 computers operating in a back-to-back arrangement via a data coupling channel. Each CPU is equipped with such peripherals as a teletype and a cartridge disk drive subsystem for mass storage of data. A line printer and paper tape reader/punch is connected to the secondary CPU for data retrieval and software development. Six process interface controllers (PIC's) are connected to both CPU's for redundancy so that the secondary CPU can assume full process control upon failure of the primary processor. Each PIC, in like manner, is redundantly connected to other PIC's thereby providing backup in case of a PIC or channel adapter failure. Six channel adapters together with their modem and line switch are located in each PIC. Each modem/line switch combination is capable of handling up to six 4-wire leased telephone circuits.

At the start of this project, "telegraph-grade" telephone circuits for interconnecting the remote terminals with the dispatching office were considered because of their attractive low leasing costs. However, this idea was abandoned early in the game as Bell engineers advised that such circuits were difficult to make up on a party-line basis and have reliability problems. A major criteria was the fact greater speeds than could be accommodated by telegraph-grade circuits were needed for handling the vast amount of data transmission required for this supervisory system. The Company's own microwave system will be utilized to augment the Bell leased lines wherever possible.

The communication circuits will be half-duplex, full period, 600 ohms balanced, Bell designation 3002 and unconditioned. This allows us to utilize a transmission speed of 600 baud and maintain a 15 second scan time on all data acquisition and a 5 second scan time of all status devices.

Should each of the substations be brought into the master terminal via a leased telephone line, the cost would be prohibitive. Therefore, a "party-line" arrangement, where more than one substation is coupled to any one line was chosen. Much study was given to the number of substations that should be placed on any one circuit. Here leased line costs must be weighed against the impact of having a number of substations out of service at any one time. Union Electric decided that no more than 6 substations should be party-lined on any telephone circuit. It is recognized that this philosophy will vary greatly from any one company to another.

Because the communications link would be one of the most vulnerable and exposed elements in the supervisory system, a rather sophisticated error detection scheme is required in the coding. Bose-Chaudhuri error detection is used because these codes were available in most vendor's systems. They possess good efficiency and a high degree of confidence required in remote-to-master communications.

In order to protect this telephone circuitry from failure due to rise in ground potential due to fault conditions, it is mandatory that all telephone circuits leaving or entering a substation property be provided with neutralizing or isolating transformers. Under Bell's new tariff provisions, this protection can be provided by either the telephone company or the power utility. For economic reasons, Union Electric decided to provide this feature ourselves.

Control Data type 44-500 remote terminals are at each of the substations in the supervisory system. This is a high-speed continuous scanning unit that communicates with and is controlled by the computer master. It provides status and set-point output to control a broad range of digital or analog devices. Also, it provides an indication of device status and numerical values of pulse accumulators and analog quantities.

Union Electric placed stringent demands upon the physical location and environmental conditions under which the remote terminal equipment must operate. While the master and the remotes may be separated by great distances, the remote terminal, must of necessity, be located adjacent to the substation equipment it is supervising and/or controlling. Little space is available within the metal-clad switchgear at a distribution substation in which the remote terminal is to be installed. When installed, the terminal cannot infringe upon the space required to draw out breakers. Remote terminal equipment is normally contained in a 30 inch (76 cm) square cabinet 72 (183 cm) to 90 inches (230 cm) in height. This cabinet was redesigned to fit in a space only 14 inches (36 cm) deep by 24 inches (61 cm) wide by 80 inches (210 cm) in height. Also, the enclosures had to be weatherproof, (as some are mounted outside of the switchgear) and capable of operating within temperature ranges of -20°C to 70°C and at humidity of 0 to 90 percent, non-condensing.

The remote terminals are also designed to be readily expandable as more control points are added in the future. As new bays of equipment are added at a substation, additional points must be added in the remote terminals. The basic design of the remote terminal is such that only additional cards must be inserted into prewired baskets to accommodate this expansion. No external wiring is required at the remote terminals. For the most part, all that is required at the master terminal is a software change.

The large number of remotes scheduled for the system also presents a documentation problem. If each of the remote terminals were designed individually, nearly 200 sets of different documentation would be required initially. However, we have been able to reduce the different number of remotes to 4 basic types, each similar differing only in the number of control points required. This grouping allows the manufacturer to take advantage of the economies inherent in common parts and production.

Back at the master terminal is where the CPU's and their associated peripherals are located. In the Distribution Dispatching Office (DDO) at this location, four supervisory operating positions will be installed. These are the "man/machine interface" positions. Each position consists of a communication turret housing, all telephone and radio control facilities, two cathode ray tubes (CRT's) for display purposes, operating keyboard and logging typewriters. The CRT's are 19" (diagonal measurement), 7-color and capable of limited graphics display.

There are 5 such control consoles. Four are located in the DDO and one is located in the Load Dispatching Office (LDO). The LDO's console is slightly different in that the communications portion is not included as the LDO has its own communications set-up. One control position is provided for all remotes in the "Central" (city) area, another the "North County" area, another the "South County" area and another the "regional area". By button selection, a console can assume operation in any of the above-mentioned areas or can be made to operate in parallel with any other console. The LDO console's operation is slightly different in that it will handle only the substations for which the LDO is responsible.

The supervisor's keyboard associated with each console position is used for any supervisor selection or entry. The keyboard has two "channel select" buttons which allow it to be switched between the two CRT's, thus allowing control or selection from either CRT; but not simultaneously. The two CRT displays at each supervisor's console have separate display memories so that they can operate independently and the CPU can, therefore, write separate formats on each display with no interaction between the CRT's.

The substation is the basic unit for display. Each substation is represented by a one-line diagram showing the position of all controllable devices and data quantities obtained from that station. All information obtained from the on-line data base (software) is up-dated dynamically on the one-line diagrams. Selection of a station for display is based on the "menu approach". There is a menu corresponding to each of the operation areas; i.e., Central, Regional, North County, South County and LDO. A menu will be displayed at any CRT not being used for other purposes. The particular menu being displayed will depend on which of the operational area keys has been depressed. The LDO console will always present the LDO menu.

A room, contiguous to the DDO, will house CPU's, peripherals and engineer's console. The engineer's console will consist of a single CRT and full keyboard and will be used by the engineer for program development and modification to one-lines, etc. This engineer's console will be used not only in the programming effort; but also to train new personnel and to implement maintenance procedures. The engineer's console has the same capability as an operating console for selecting, displaying and controlling a remote terminal. It can, however, also be utilized in a training mode where a trainee can select and display any remote terminal on the system. It may also be used to control a remote terminal, provided that the key interlock to the control section of the engineer's console has been enabled.

The software associated with this supervisory system can be divided into 3 basic categories -- (1) standard operating system, (2) standard driver packages, and (3) special application software. The standard operating system, such as the Mass Storage Operating System (MSOS), enables the user to begin a system design within the framework of already existing statements, instructions and functional capabilities. The MSOS was selected because it is real-time oriented and interrupt driven. Other standard software packages such as scan, control, alarm, display and logging are also used, each tailored to fit Union Electric's system. Special application software designed for the system includes such things as logging, method of displaying and alarming and coordination of the data base with the man/machine interface. Two unique software packages are provided with our system. One is the On-Line Display Generator and the other is the On-Line Data Base Manager.

The On-Line Display Generator permits the engineer at his console to draw a one-line on the CRT and enter it into the on-line system. There, it is automatically linked to data previously entered into the data base via another unique software package called the Data Base Manager routine. The On-Line Display Generator is a mass memory resident program that executes upon demand in the SC-1700 CPU. The primary function of this program is to provide the means of building and maintaining the current file of CRT displays which contain both fixed and dynamic information.

The On-Line Data Base Manager Program is mass memory resident executed on demand in the SC-1700. The primary purpose of this software package is to provide a means of updating and expanding the software system. It is not intended that this program be used by the console supervisors; but rather it be used by the engineer using the teletype as the input media. The On-Line Data Base Manager Program allows the engineer to:

(1) Enter new points and/or stations to the system.

(2) Modify previously defined points and/or stations in the system.

(3) Enter system data files which have previously been punched in binary format.

(4) Dump system data files in binary format on paper tape.

Complementing the On-Line Data Base Manager Program is the Library Editing Routine (LIBEDT). This program allows the addition, modification or deletion of functions to the system. LIBEDT can make the following changes to either the system library or program library:

(1) Add a program.

(2) Remove a program.

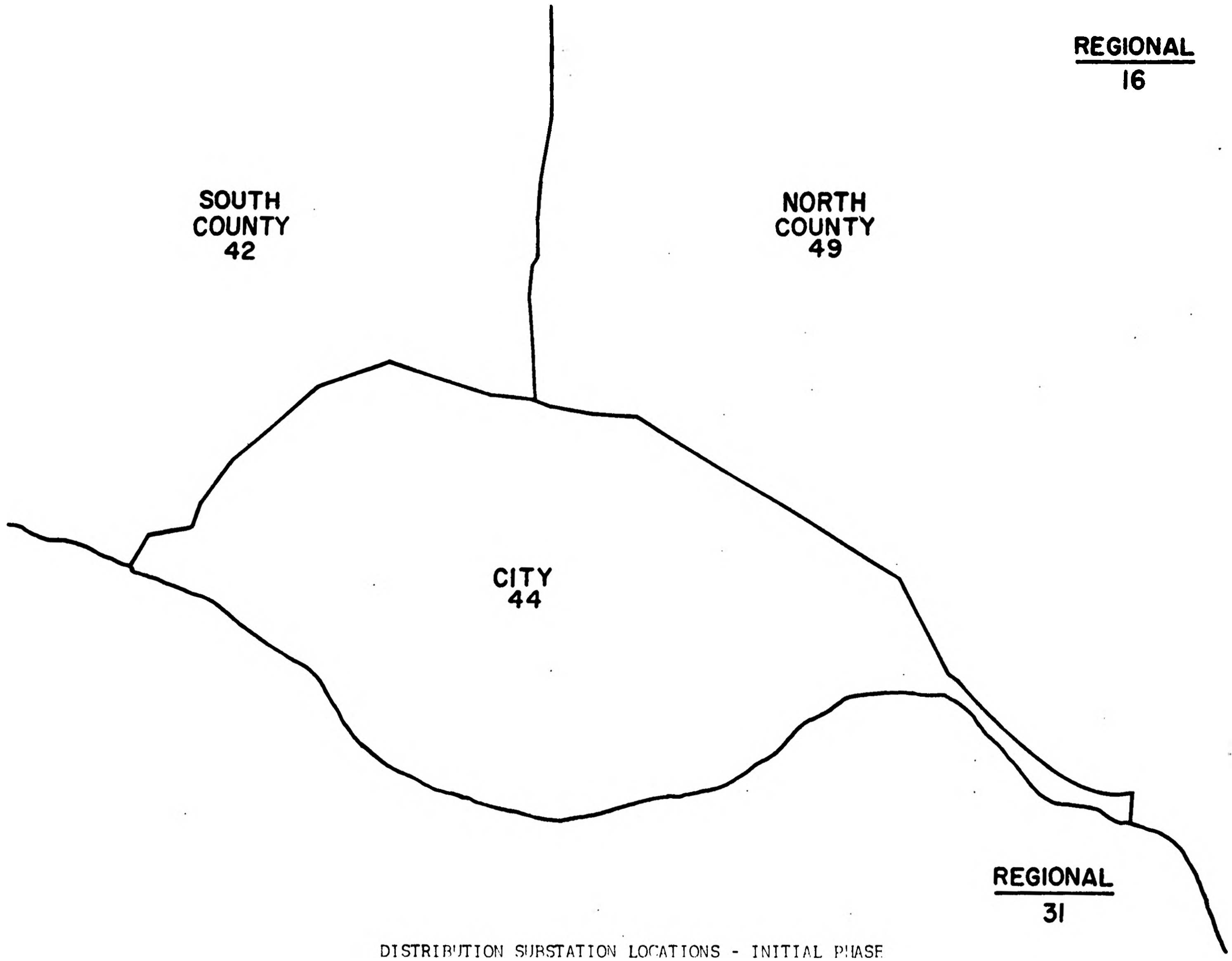
(3) Replace one program with another.

(4) Combine several relocatable programs from the library program or from an input device into an absolute format and then output them as a binary record on the binary output device.

CONCLUSION

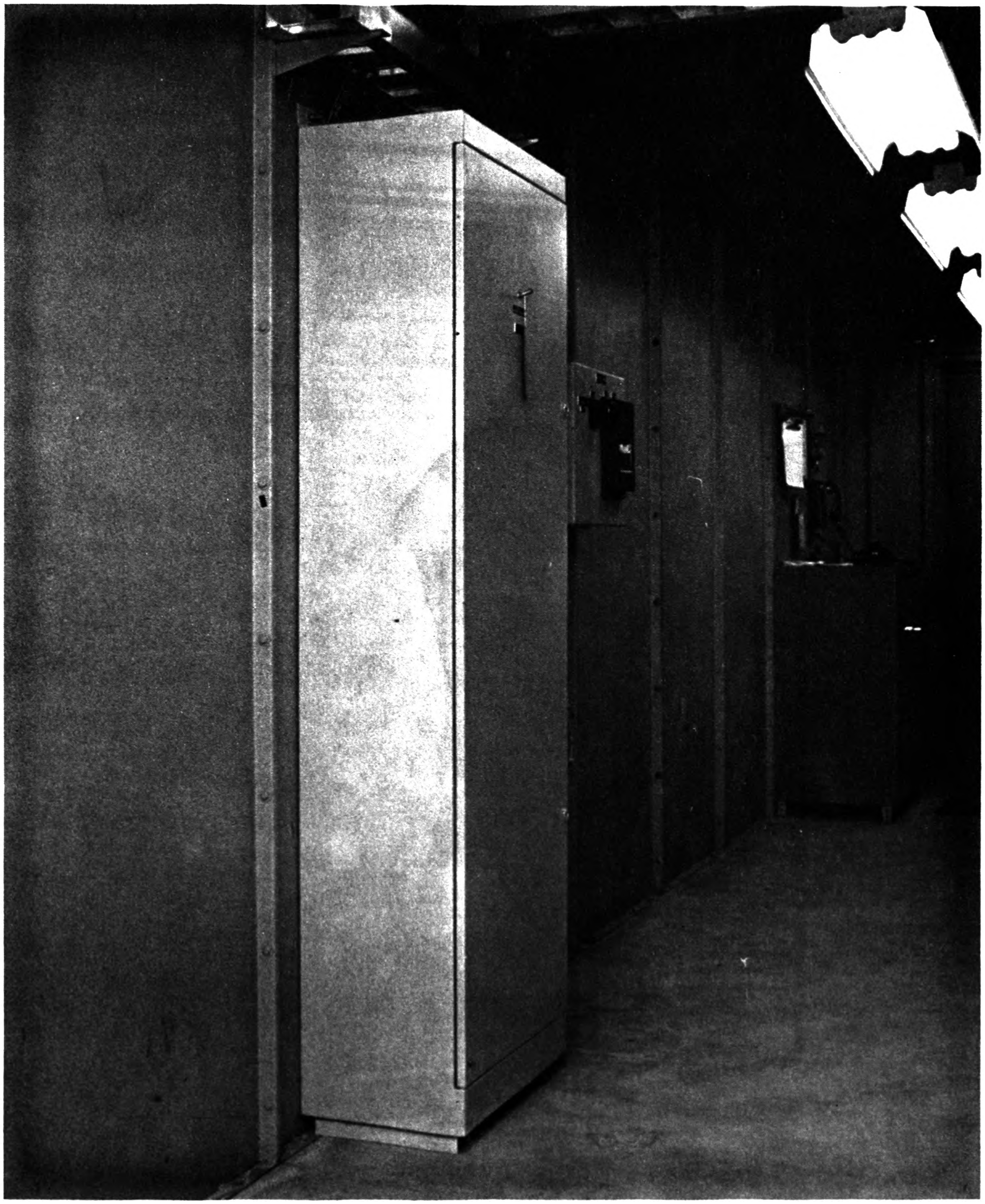
A number of remote terminal units have been installed by Union Electric field personnel. A considerable number of remotes as well as the CPU's and all its peripherals have been retained in Minneapolis by Control Data Corporation where the equipment is presently undergoing rigorous testing of both hardware and software.

Delivery of the system is anticipated for mid-summer 1974. After on-site debugging and installation, operation of the first phase of the system; i.e., master station equipment with presently installed remote terminals, will begin. As remote terminals are installed at the various substations, they will be added to the system. Initial on-line operation will begin early fall 1974.

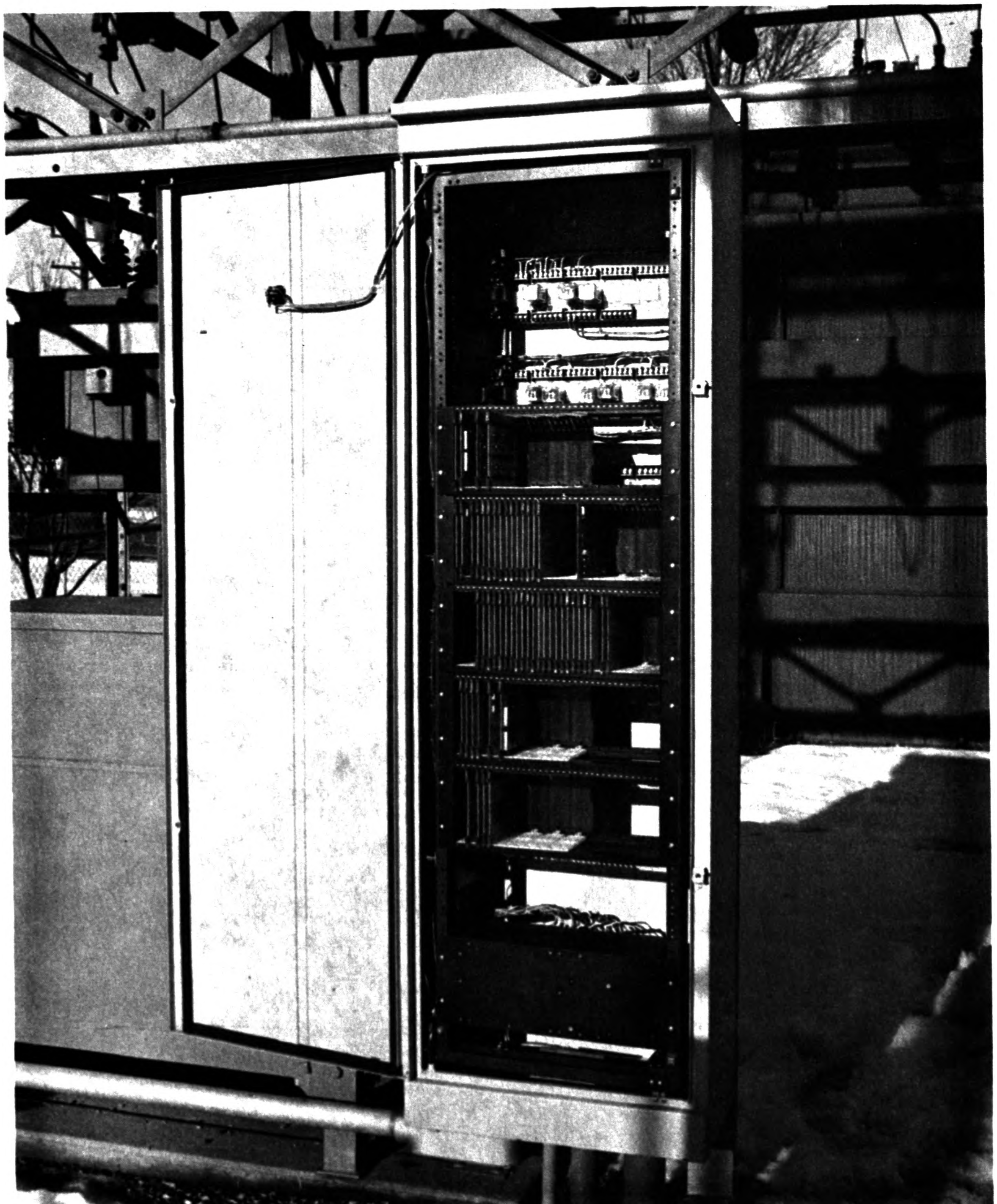


DISTRIBUTION SUBSTATION LOCATIONS - INITIAL PHASE

REMOTE TERMINAL INSTALLATION - OUTDOOR



REMOTE TERMINAL INSTALLATION - INDOOR

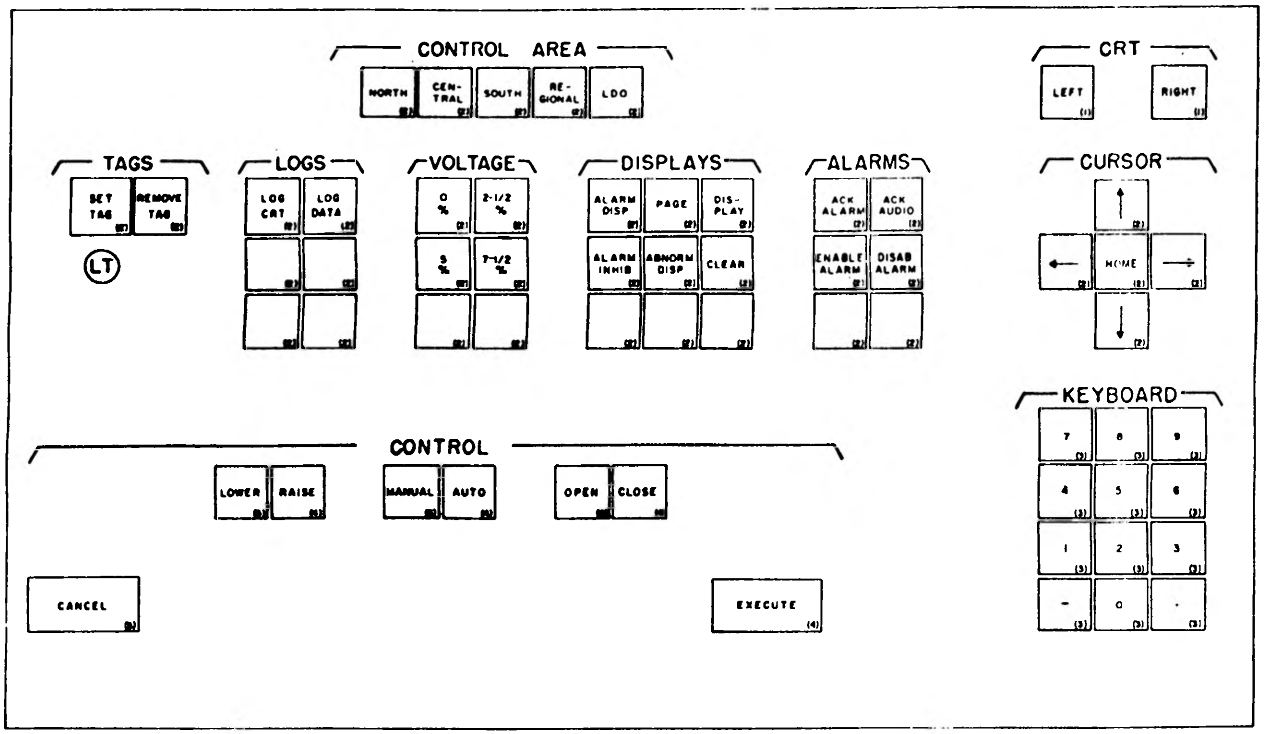


REMOTE TERMINAL - FRONT VIEW
(NOTE ROOM FOR FUTURE EXPANSION)

REMOTE TERMINAL UNIT - INSIDE VIEW
(NOTE ROOM FOR FUTURE EXPANSION)

8324-Z-72699

923

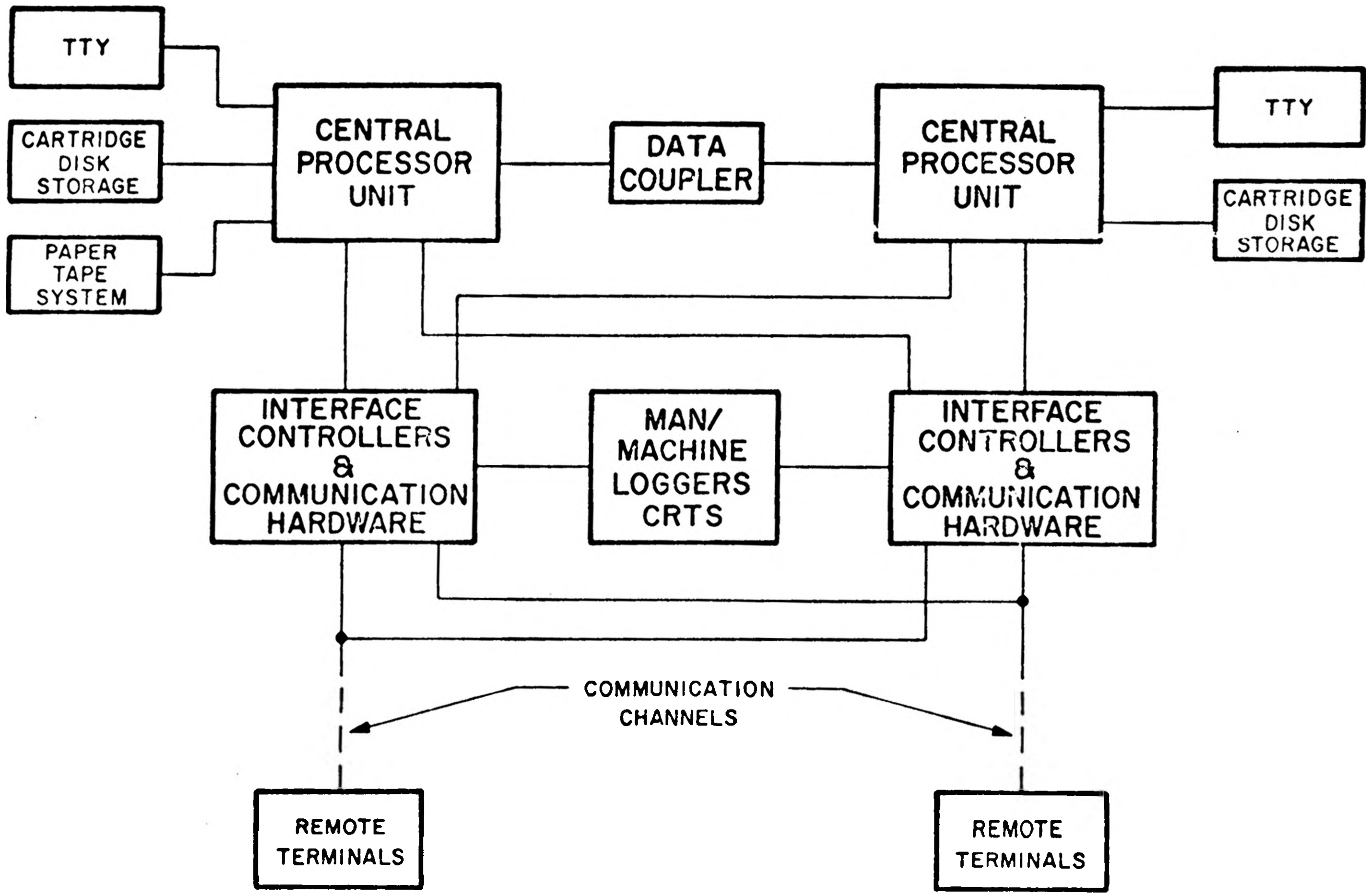


NOTES:
(1) ORANGE ILLUMINATED
(2) DARK GRAY
(3) LIGHT GRAY
(4) RED
(5) GREEN

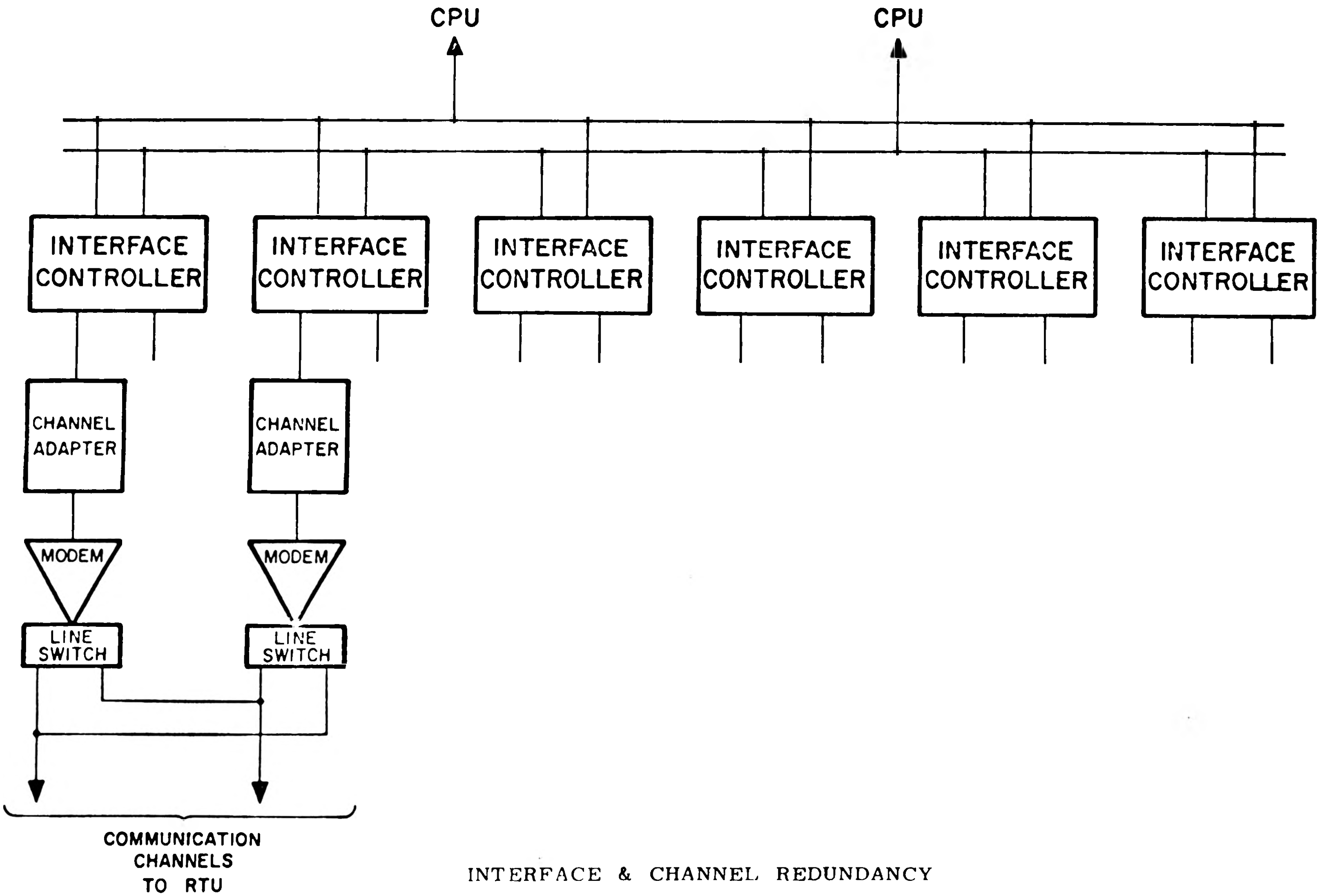
SUPERVISOR'S CONSOLE
KEYBOARD ARRANGEMENT
DDO OFFICE

UNION ELECTRIC SYSTEM ST. LOUIS, MO.
LOCATION GRATIOT ST. DDO

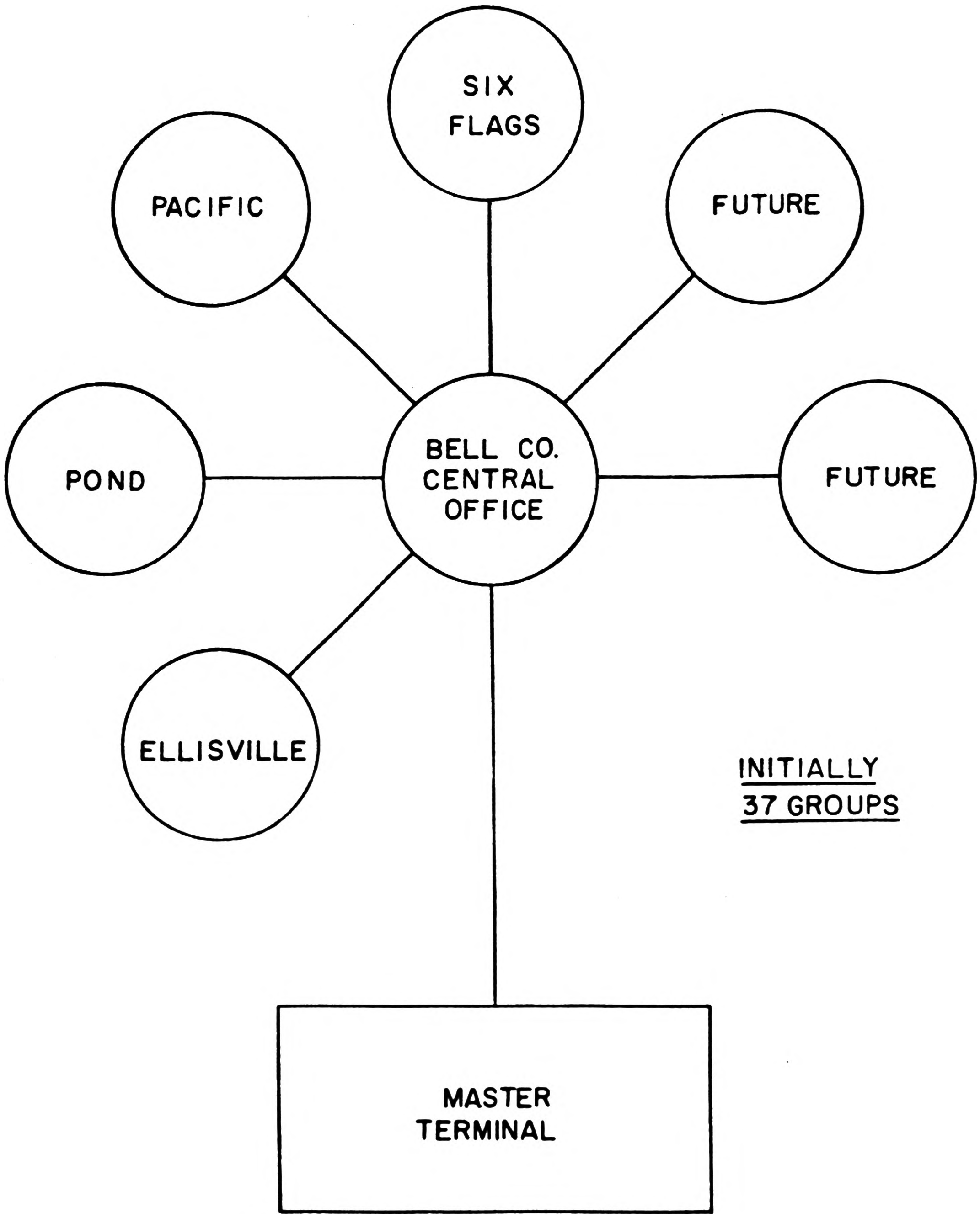
8146-Z-72699

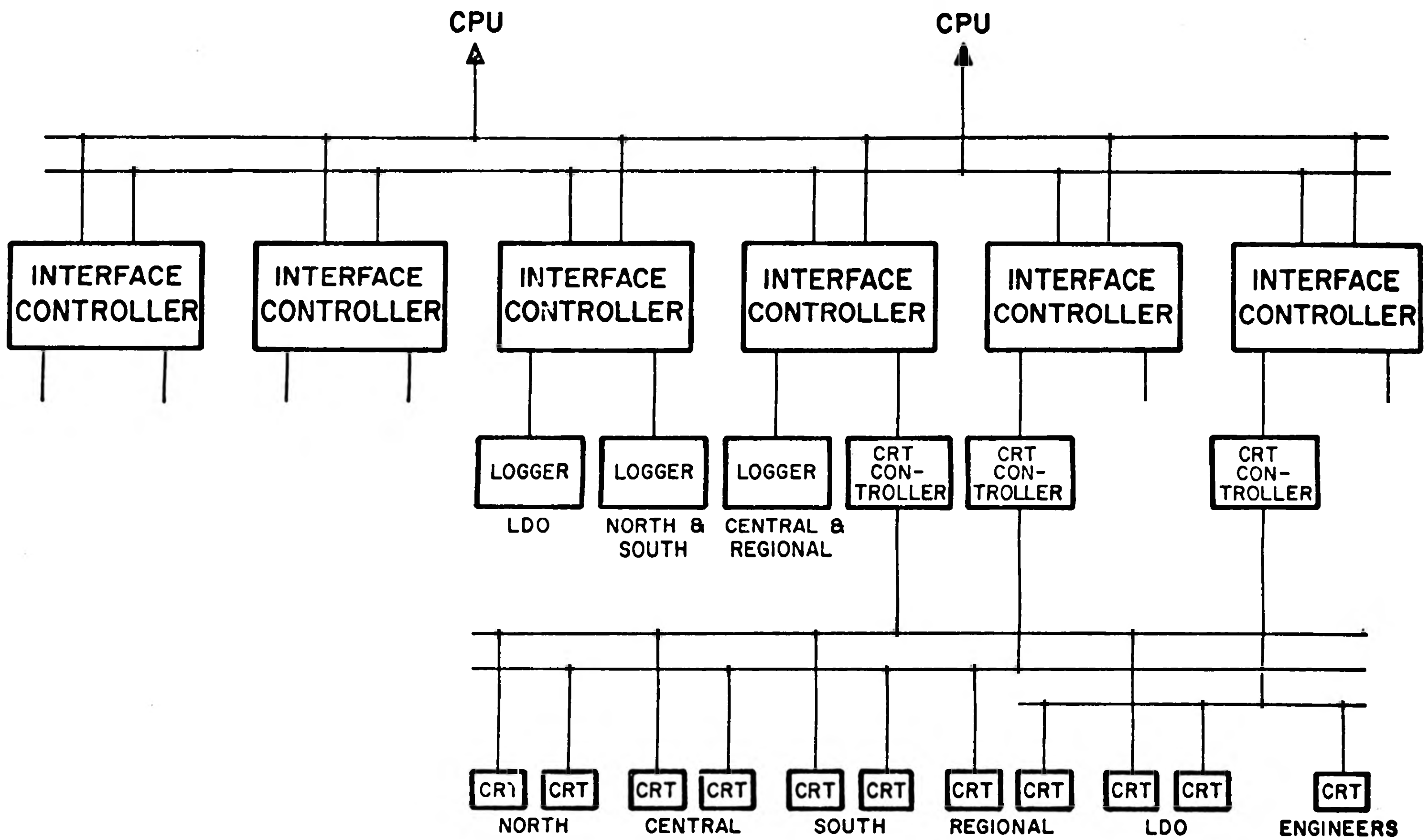


SYSTEM OVERVIEW



INTERFACE & CHANNEL REDUNDANCY


SIX
FLAGS
PACIFIC
FUTURE
POND
BELL CO.
CENTRAL
OFFICE
FUTURE
ELLISVILLE
INITIALLY
37 GROUPS
MASTER
TERMINAL



MAN/MACHINE INTERFACE HARDWARE

MINI-COMPUTER CONTROL OF ELECTRICAL ENERGY DEMAND

By

Thomas P. Hertel
Meramec Mining Company
Sullivan, Missouri

ABSTRACT

Electrical power demand control results in huge dollar savings for the medium to large user. Meramec Mining Company realizes an average \$4,500.00 savings from an average \$150,000.00 monthly charge because of demand control efforts.

This paper discusses the planning, designing, implementing, and auditing of the mini-computer system at Meramec Mining Company. No detailed discussion of the actual computer coding is included.

AUDITING PROGRAM FOR EFFECTIVE ENERGY CONSERVATION

S. Noble Robinson

Mallinckrodt Chemical Works
St. Louis, Missouri 63147

ABSTRACT

Mallinckrodt Chemical Works has developed and is using a special audit format to identify conservation opportunities for all its utilities. Manufacturing, Utilities, R & D, and Engineering personnel are collected together for several days during which time a process or operation is subjected to an intense analyses of its utilities consumption, a brain-storming of conservation ideas, and then an "on-the-spot" engineering analysis of the economics and feasibility of each idea. This technique is a fast, comprehensive way to assess conservation potentials while committing the attention of those operating groups that can implement the ideas.

INTRODUCTION

In this period of uncertain energy supplies and escalating energy costs, many corporations have established formal conservation programs. These programs have taken various forms, but all of them require that conservation opportunities be specifically identified before money and effort can be spent to implement them.

In manufacturing, and specifically in the chemical industry, the general techniques for achieving improved energy usage are well known. The problem, then, is to identify those parts of an operation or process where the techniques can be economically applied. One method, of course, is to assign an engineer to the task and let him systematically measure steam flows, power input, etc.; develop conservation ideas; then test them in depth for viability. This is thorough but it has two failings. The engineer focuses only one mind and one set of experience on the problem. Second, the ideas are his - not those of the operating group - and getting them implemented requires that the "not invented here syndrome" be successfully overcome.

This paper describes an alternate technique - one that draws on the experience and creativity of several technical disciplines; that is quick and versatile; that not only generates ideas but immediately tests their value; and that relies heavily on the operating personnel so that they are committed to the results.

AUDIT FORMAT

The major ultimate objective of the Energy Conservation Audit is, of course, to reduce energy use. But the Audit itself, as conducted at Mallinckrodt Chemical Works, is dedicated to the objectives listed in Table 1.

An important subordinate result of the audit is an assessment of the vulnerability of the product or operation to problems caused by the energy shortage. For example, if the add-on energy required to manufacture the product is relatively low (less than 10,000 BTU/lb.), then the product is somewhat secure from the impact of rising fuel costs. Or, if the process uses interruptible natural gas, then it may be vulnerable to shutdown if there is no alternate fuel.

Table 1

Objectives of Energy Audit

1. Identify conservation opportunities for all major and minor utilities.
2. Estimate the financial and non-financial benefits of the ideas.
3. Establish a working list, by priorities, of opportunities to implement.
4. Identify future vulnerabilities caused by the energy shortage.
5. Estimate the add-on energy requirement per pound of the product.

To achieve these objectives, a formalized audit format has been devised, and the entire procedure is outlined in a manual used by the participants. The manual defines the procedural steps to be followed, and it contains "rule-of-thumb" calculation techniques to help in the economic evaluations. Further, it has conservation ideas and the data required to evaluate the ideas for every major unit operation or type of equipment found in Mallinckrodt's plants, as the examples in Table 2 show.

Table 2

Typical Conservation Ideas

Dryers, Gas Fired

a. Opportunities:
   1) Use of proper air-fuel mixture
   2) Heat recovery from stack gases
   3) Increased insulation
   4) Decreased moisture in product feed
   5) Hot product discharge
   6) Reduced operating temperature
   7) Increased gas/solid contact
   8) Recycled hot air

b. Required data:
   1) Orsat analysis and stack temperature at discharge from burner box
   2) Fuel consumption (or burner data)
   3) Total gas flow
   4) Discharge gas temperature
   5) Dryer design drawing
   6) Outside surface area
   7) Surface temperature
   8) Insulation thickness
   9) Discharge air humidity
   10) Product flow rate
   11) Product moisture
   12) Drying curve
   13) Feed moisture

There are eight major steps in the conduct of an audit, and they are managed by one person acting as the leader.

First, he must coordinate with the various departments, especially operations, to determine which process or operation is to be audited. Then he must resolve an extremely important issue - who shall participate. The ultimate success of the audit is directly proportional to the quality and experience of the participants, and the leader should seek the best people available from operations, R & D, engineering, and utilities. The total number of participants should vary between four and eight, and each should be prepared to commit his time totally to the audit.

Recruiting of personnel, setting of a time and place for the audit, and completion of other preliminary details, represent a complicated logistics problem, with plant emergencies, competing priorities, and variations in enthusiasm coming into play. These factors will ultimately require about twenty per cent of the leader's time investment in the audit.

Next, the leader meets with all the participants to define the purpose of the audit and to distribute data collection assignments. In addition to operating data, such as insulation thicknesses, flue gas analyses, etc., it is necessary to calculate the current and projected costs of the pertinent utilities. Further, it is important to identify direct utilities costs and "top-of-the-rate" costs since these will define potential savings.

About two weeks is allowed between the preliminary meeting and the audit for data collection, and if any participant is unfamiliar with the process, for plant tours. Although it is not important that all the participants, especially the leader, be thoroughly knowledgeable about the process, it is important that everyone has seen the area, the equipment, and the operation.

After the audit is held, the leader then prepares a report summarizing the conservation ideas that are worth implementing; the add-on energy consumption per pound of product; and the future vulnerabilities. This report then serves as the working document for a meeting between the leader and the management of the operating section. The main purpose of the meeting is to agree on the ideas that will be pursued further and who will be responsible for their management. Some ideas are procedural, and can be handled totally by manufacturing. Some require research and development. Most require capital investment and must ultimately be handled through the engineering groups. The responsibility for their implementation, however, passes from the leader to the operations management.

This, of course, is the end of the audit, but not the end of the formal program. Follow up is necessary to insure that the ideas come to fruition. Some may be abandoned after more in-depth engineering study, but the major danger is that the ideas may stagnate because of lack of attention.

These major steps of the program are summarized in Table 3.

The audit itself is conducted by the leader, who acts to short-circuit non-productive ideas, to minimize idle conversation, and, in general, to keep the group focussed on the objectives. The audit may last two or three days, and the effort is intense, so the leader must maintain good discipline and interest if the audit is to be successful. The steps of the audit itself are outlined in Table 4.

Table 3

Major Steps In Audit Process

1. Establish time and location
2. Identify participants
3. Hold preliminary meeting
4. Collect required data; tour facilities
5. Conduct the audit
6. Prepare summary report
7. Assign responsibilities for implementation
8. Follow-Up

Table 4

The Audit

1. Introductory Remarks
2. Overall Review of Flow Sheet
3. Step-Wise, In-Depth Review of Flow Sheet
    a. Identification of Utilities Usage
    b. Brainstorming for Conservation Opportunities
    c. Evaluation of Opportunities
4. Review of General Utilities Usage
5. Summarization
6. Identification of Future Vulnerabilities
7. Estimation of Product Add-On Energy Use

The introductory remarks include background information on the energy crisis as well as an appeal for creative openness - without cynicism or negativism - on the part of the participants.

Then the operating personnel review the total flow sheet for the operation, partitioned according to the steps defined in the preliminary meeting. This is followed by an in-depth consideration of each step. The total consumption of each utility is identified, with the leader noting this and subsequent ideas and calculations on easel paper, posting the critical sheets around the room for quick reference.

After an operating step is thoroughly reviewed, then the participants brain-storm conservation ideas, drawing from the ideas listed in the manual or using their own initiative. All the ideas are written down. Then the leader takes the group through a systematic analysis of each idea. The potential savings are calculated, using rule-of-thumb techniques and general engineering experience. The capital investment is estimated, too, and if the capital can be retired in five or less years, then the idea is further analyzed for other negative or positive benefits, for its probable duration, for its ease and timing of accomplishment, and, finally, for its technical practicality. This activity is time-consuming, and, with experience, the leader can avoid extensive analysis of marginal ideas.

After each operating step is reviewed, then the same analytical approach is applied to the general utilities usage of the physical area where the process is housed. This includes, for example, the heating and ventilating system, cooling towers, air pollution control equipment and lighting.

Depending on the operation, the leader may want to brain-storm major changes in the operation, such as basic changes in the process chemistry, and evaluate their conservation worth. This usually leads to long-term programs, but it helps focus immediate attention by the R & D and operating personnel on the energy implications of various fundamental process changes.

Usually toward the end of the audit, the leader works with the participants to develop the list of energy-oriented vulnerabilities. The last two tasks, summarizing the results and calculating the total add-on energy used by the product, can be done during the audit. However, these tasks can be done more efficiently later by the leader alone.

RESULTS

Each audit is likely to be different in scope and productivity. However, Tables 5, 6, and 7 present typical results from an audit of Mallinckrodt's process for manufacturing Barium Sulfate USP, a compound used for X-ray diagnostic purposes.

Table 5 clearly illustrates the relative cost of the various utilities used in this process. It also identifies the utilities cost per pound of product, which can be related to the total product cost. At 28,624 BTU/lb. $BaSO_4$, this product is energy intensive, and this alerts the operating personnel to the vulnerability of $BaSO_4$ USP to escalating steam costs and fuel shortages, and it gives impetus to implement the conservation ideas that were developed.

These ideas are in part illustrated in Table 6. The cryptic notes are indended to identify the scope of the idea; a more thorough description must be sought in the audit notes. The estimated five year savings are based on the sum of various utility savings. For instance "Return vac. quench H_2O to QW Tk." involves recycling quench water used in the barometric leg of a vacuum producer back to another process quench water tank where currently fresh water is heated to 80°C. The idea not only conserves steam, it also conserves water and reduces sewage treatment costs.

Some of the vulnerabilities are noted in Table 7. It was determined that a critical scrubber blower was made of a fiberglass-resin compound that had been in short supply, and it was determined that a spare should be immediately ordered. Barytes, the impure $BaSO_4$ used as the principal raw material in the process, is also used as a weighting agent in drilling mud used in oil fields; therefore, its procurement should be closely watched.

It has cost between $2,000 and $5,000 to conduct each audit. The Barium Sulfate audit cost $3,700. It developed $178,500/year in potential utilities savings.

TABLE 5

Examples of Results - $BaSO_4$ Audit

Total Utilities Cost - 1973 (USP Process)

Operation	Steam lb./Day	H_2O gal./Day	Elec. KW hr./Day	Comp.Air MCF/Day	Nat.Gas MCF/Day
Cooker	43,700	47,500	820	43.2	
Filter/Digest	38,400	30,600	330		
Filter/Reslurry	28,000	38,900	340		
Dryer	55,200		555	14.4	
$CaCl_2$ Conc.	213,600	6,000	260		
Proc. Exhaust		7,200	1,250		
Misc. Utilities			290		36.7 (winter only)
Total	378,900	130,200	3,845	57.6	36.7
1973 Cost	$1.33/M lbs.	$.225/M gal.	1.41¢/KWH	7¢/MCF	68¢/MCF
Daily Cost	$504	$29	$54	$4	$10 (Avg. over yr.)

Total Daily Cost = $601

¢/lb. $BaSO_4$ = 2.81

Total Equivalent Energy Use (USP Process)

Steam, Based on Boiler Feed:	27,276 BTU/lb. $BaSO_4$
Electricity:	620 BTU/lb. $BaSO_4$
Natural gas:	728 BTU/lb. $BaSO_4$
	28,624 BTU/lb. $BaSO_4$

TABLE 6

Examples of Results - $BaSO_4$ Audit

Conservation Ideas (USP Process)

Step	Opportunities	5-Year Savings	Required Capital
Cooker	Recycle LP steam, jets to QW Tk.	$35,000	$ 2,000
Cooker	Use electric vs. air vibrators	3,600	1,500
Cooker	Use 5% $CaCl_2$ as QW	61,200	10,000
Filter/Dig.	Return vac.quench H_2O to QW Tk.	17,500	2,000
Filter/Dig.	Eliminate one digest Tk.	21,300	1,000
Filter/Resl.	Heat wash H_2O-ht.exch. on Stg.2 jet	10,000	1,500
$CaCl_2$ Conc.	Recycle Filter M $CaCl_2$ as $CaCl_2$ make-up H_2O	46,000	15,000
$CaCl_2$ Conc.	Raise $CaCl_2$ to 35%	42,000	1,000
Misc. Util.	Recycle bldg. warm air	10,000	1,000

TABLE 7

Examples of Results - $BaSO_4$ Audit

Future Vulnerabilities

1. Barytes
2. Cardboard Containers
3. Filter Cloths (Cotton, Synthetic)
4. Nickel Agitators
5. Hastelloy Steam Blow Lines
6. Filter Agitator
7. Plastic Scrubber Blower

This is equivalent to a preliminary cost of 2% of the potential savings, which is considered a good investment. However, not all operations will prove as productive, and the cost of the audit cannot be lowered significantly without sacrificing the advantages of speed and multi-disciplined involvement. So some selection process should be used to identify the operations within a company that are likely to be most energy-inefficient.

In general, the audit program has been successful in identifying practical and economically justified conservation ideas. It has been modified slightly with experience, but it has proved to be a strong engineering-management tool.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the participation of Mr. Edward Stewart and Mr. Richard Hamilton of Bataille Associates, Inc. in the development of the audit format.

MONITORING AND CONTROL OF ELECTRIC POWER USAGE

By

Robert B. Webb
Armco Steel Corporation
Kansas City, Missouri

ABSTRACT

At the Armco Kansas City Works the consumption of Electrical Power is monitored and controlled by a General Purpose Computer located in the Electric Furnace Dept. This computer monitors the power used in the entire plant through the power metering system. The computer can limit the power to the electric arc melting furnaces and in this manner control the demand level during peak hours. The computer can also detect meter failures. The computer system collects data which enables management to detect and analyze variations in electrical power consumption.

MONSANTO'S ENERGY CONSERVATION PROGRAM

Ray E. Doerr
Engineering Director
Corporate Energy Conservation Program
Monsanto Company
St. Louis, Missouri

Energy conservation is not new to Monsanto. We have had utility and process improvement programs for many years. But the motivation of these programs was to reduce our operating costs and improve profits. However, these programs did result in substantial energy savings.

Now, however, Monsanto is placing major emphasis on a broad-scale energy conservation program for all Monsanto locations. The energy saving potential is great and is necessary because of the energy shortage as well as the rapidly escalating energy costs.

Before going into the details of our corporate energy conservation program, I want to summarize the energy conservation actions taken by Monsanto.

1. Top management has established energy conservation principles and goals.

2. A Corporate Vice President of Energy and Materials Management has been elected by Monsanto's Board of Directors.

3. A company-wide Energy Conservation Program has been instituted. To help monitor conservation results, each location must make periodic progress reports.

4. We have developed employe awareness programs covering energy conservation needs in all plants, offices, and laboratories. The main thrust of this has been through the plant energy conservation task force, plant newspapers and the goals program. We have just completed a 25 minute 16 mm film on "Energy Conservation Opportunities In Monsanto". This film will be shown in all of our plants. In this film, Mr. J. W. Hanley, President of Monsanto, strongly emphasizes the conservation program.

5. Special engineering thermodynamic reviews are being made by our Corporate Engineering Department of all proposed new facilities. The purpose of these reviews is to insure that maximum energy conservation steps are designed and built into new facilities. In line with this, we have also established a reporting system, covering energy utilization improvements made by our engineers in the design of new projects.

6. Research is being conducted on high energy production processes with the aim of reducing energy requirements or producing new, low energy processes.

7. We have established a Long Range Energy Planning Group to identify, evaluate and recommend optimum energy utilization steps and techniques for the 1980's. This group must determine Monsanto's energy needs 10, 15, or 20 years from now and determine where Monsanto will obtain these energies.

8. Monsanto management has committed qualified personnel full-time to each phase of the program.

Last year, Monsanto formally approved a Corporate Energy Conservation Program. As coordinator of the Corporate program, I report to a Corporate advisory board made up of six people. Monsanto has four operating companies. Each of the four companies has an energy coordinator on the advisory board. Also the director of Long Range Energy Planning and the director of Corporate Engineering Technology, Design and Construction is on the board. Each operating company is responsible for the implementation and management of their plants' conservation programs.

Monsanto has 45 plants in the U.S. In 1973 our purchased energy bill totaled over $100M̄, excluding feedstocks.

In 1973 our conservation program resulted in a 6% reduction in our energy consumption rate per unit of product. Monsanto's goal for 1974 is to reduce our energy consumption rate per unit of product output by 10% as compared to 1973. This additional savings in 1974 will not come easily but it is obtainable.

I want to briefly review the meaning of the 1974 goal. For example, in the process area in 1973, if it took 10M̄ BTU's of steam to produce 100 pounds of product, to meet the 1974 goal the steam consumption rate will have to be reduced to 9M̄ BTU's. We are to report our energy savings in equivalent purchased energy units. Therefore, the 1M̄ BTU steam savings will save 1.3M̄ BTU's of purchased gas and 2 KWH of purchased electricity. This example could have been gas, oil, coal, electricity, refrigeration, or any other energy source. This goal also applies to energy used in the production of utilities.

This energy rate savings goal can also apply to warehouses and office buildings, like Monsanto's General Offices in St.Louis.

One approach is to use steam or refrigeration per degree day, and if you add any additional building space, base the energy rate on degree day per unit of building volume such as 1,000 CF. This past winter Monsanto's General Offices in St. Louis used 22% less steam than we did the prior winter, using the degree day method. This was brought about by lowering thermostat setting, minimizing fresh air make-up, balancing the heating and cooling systems, and shutting down the heating system during nights and weekends.

To communicate the total program to all 45 Monsanto plants as well as expedite Monsanto's plant-wide program, a "Recommended Approach To A Plant Energy Conservation Program" was prepared and issued to the plants. Over 300 copies of this program have been distributed by the coordinators for use within the plants. A similar report has been issued to our plants in Europe, Canada, and Australia. This report recommends a systematic approach for organizing and implementing a plant conservation program. Also, it outlines a systematic approach for determining energy conservation opportunities.

In this report we recommended that one of the first steps a plant should take is to make a plant energy survey to know where each type of energy is being consumed and where the unaccounted for losses are within the plant distribution system. Both type of energy and quantities consumed should be established. This survey results in a plant energy balance.

Concurrently with this, a systematic approach was outlined in the plant program to:

1. Identify immediate changes where improvements in operating practices would result in energy savings. For example, improving the combustion efficiency by optimizing fuel air ratio.

2. Establish plant maintenance practices relative to energy conservation. This phase of the program covers steam trap maintenance, steam leaks, insulation adequacy and maintenance, and steam jet maintenance.

Many of our utilities and processes were designed and built when energy costs were very low as compared to energy costs today. Therefore, there are many opportunities for energy savings requiring capital investment. This capital can be justified based on the energy savings. To establish where these opportunities are, energy audits must be made of large energy consuming processes and utility systems to determine where the energy is being consumed within the process, where energy is being rejected, how efficient the energy is being used, and where energy can possibly be recovered that is presently being rejected to the atmosphere or cooling water. Also, new technology or new catalyst may be available that will reduce the energy consumption rate. This is especially true if the department was built several years ago.

For a conservation program to be successful, monitoring of performance and feedback to plant operations are very important. Therefore, in our plants, tracking charts are used by plant supervision and operating personnel to help monitor energy rates of large energy consuming processes and utility systems.

Also we have instituted a quarterly progress reporting system for monitoring energy conservation results in our 45 plants. This quarterly report lists the projects or activities implemented in the plant to save energy. This information is then summarized to see what percent of the plant's 10% annual goal was achieved in that reporting quarter and year-to-date. Also those energy saving projects that have been identified for implementation at a later date are included in the report.

Earlier I made the statement that in our Corporate Engineering Department, steps have been taken to maximize energy efficiency in new projects, to reduce the energy consumption rate per unit of product. To implement this program:

1. We are presenting energy conservation workshops for our process, electrical, instrumentation, mechanical and utility engineers.

2. We are including an energy statement as a part of the capital appropriation request for new projects. The energy statement includes energy selection, availability and cost, plus a review of the energy efficiency for the project.

3. We are monitoring Corporate Engineering's contributions to the energy conservation program. To accomplish this, a system has been established for reporting design innovations and other contributions made by our engineers which will reduce the consumption rate on projects.

To instruct our plant energy coordinators on how to implement and manage a more effective plant program, we held a corporate energy conservation workshop in January of this year. The workshop was very effective and certainly was an opportunity to add impetus to the program. The information exchange between the plant coordinators was very helpful.

In a short time, Monsanto has made tremendous progress in its energy conservation program, but like most companies, we also have a big job ahead of us. But with continued management support, at all levels, which we are receiving, we will achieve our energy conservation goals. In so doing, we will be helping our country out of the energy crisis and at the same time improve profits for our stockholders.

ENERGY CONSERVATION IN THE MANUFACTURING PROCESS

Paul H. Kaiser
Emerson Electric Company

My presentation will cover the basic procedure used by the Emerson Electric Co. to conserve energy in its operations. And because people frequently tell me how much they like or dislike our television sets, and how concerned they are or are not about the depth of our involvement in furnishing material for the Defense Department, at this point I would like to give a short commercial. Hopefully, it will dispel misconceptions, and define the use of energy in Emerson's operations.

SLIDE I

Emerson is a manufacturer of diversified electrical products - motors, controls, heat, light fixtures, power tools, etc. We do not make television sets, but our Fisher Radio Division at Milroy, Pennsylvania does make super fine stereos. Operations can be broadly divided into three groups: Commercial & Industrial Components & Systems, Consumer Products, and Government & Defense business which constituted less than 2% of 1973 sales volume. Emerson has had remarkable growth, from 219 million in 1964 to 938 million in the fiscal year just ended, and is programmed to double within five years. Emerson now uses over 13 million square feet in 63 major domestic and 10 major foreign facilities.

SLIDE II

Energy costs about 1% of the cost of our products and consist of:

Oil	1%
Liquid Petroleum Gas	2%
Water	5%
Vehicle Fuel	12%
Natural Gas	22%
Electricity	58%
TOTAL	100%

The amount of energy consumed to produce our product mixture is considerably less than the industrial average. One recent study indicates that in corporations with annual sales of one billion dollars or more, the cost of energy is about 5% of the cost of the products. However, this is not meant to imply that Emerson is complacent about energy conservation. As you have seen, one of our objectives is growth. Maintaining an adequate reliable uninterrupted supply of energy at each of our facilities is an absolute necessity to achieve this objective. And the availability and reliability of the energy supplies is of utmost importance in selecting new facility locations.

Since the energy situation and the manufacturing process vary from location to location, we prefer to evaluate conditions at each facility and develop specific programs tailored to compensate for those conditions. We have office, warehouse, and manufacturing facilities. Our manufacturing facilities produce such diverse products as radio stereos requiring minimal amount of process energy for soldering and testing, to electric motors requiring considerably more for die casting, annealing, paint baking, to iron or aluminum castings substantial amounts. Further, the reliability of the primary energy source varies. Electric power can be produced from natural gas, oil, waste material or coal, or a combination thereof. Therefore, instead of adding another shopping list to the recent explosion of literature describing multitudes of ideas to conserve energy, I would like to briefly discuss three basic areas into which most conservation measures can be grouped, Reduction, Reclamation and Change.

Reduction means using less energy to manufacture current products without changing equipment, materials, methods, facilities, or processes. Examples are many and obvious; reduce facility temperatures in winter, increase them in the summer; reduce light intensities and ventilation losses; upgrade insulation and maintenance of equipment; accumulate economical lots of work ahead of process equipment, then run it at full load for a shorter period of time; reduce temperatures in washers and bake ovens; turn off machines when not in use, etc. These reductions can be achieved simply, by relying upon people to turn off lights and shut off valves, or exotically, by providing elaborate systems of modulating or regulating devices.

Reclamation means salvaging unused energy from current equipment, materials, methods, facilities and processes. Burning trash or reclaiming heat from annealing furnaces to make hot water to support other building or process operations is an example.

Change means using other materials, methods, processes, equipment facilities or energy forms to achieve the current effect. Examples are changing to a plastic part to eliminate washing, painting, or baking a steel part; converting process and facility equipment from gas to electric heat; changing to a 10 hour day four day week from 8 hour day 5 day week; changing to a total energy system using coal.

In each of these areas but particularly the last, there are opportunities - for cost reduction, developing new technology, developing new products, or improving existing products, or systems. And there are also pitfalls - increased utility rates due to decreased consumption, or flak from employees or groups who are opposed to conditions changing.

Emerson's approach to energy conservation is not unique but is based on proven business principles.

1. Management must become involved, identify responsibilities and communicate directions and results.

Energy coordinators have been appointed at each facility, each major division, and Corporate level. A Corporate Policy & Procedure on energy conservation has been developed, and dessiminated to all facilities to follow. Periodic communications in the form of memos and posters are sent all employees.

2. Pertinent information must be collected.

This includes historical data on energy consumption and cost, utility contracts, a matrix of the utility companies serving the facility and the transmission companies serving the utilities, and analyses and forecasts by the utility companies of conditions in their service areas. It also includes keeping informed of the current situation, and determining the conditions at major vendors and customers facilities.

3. Analyze and evaluate the data.

This includes a forecast of energy requirements for new and existing facilities, capability of utility companies to meet the requirements, effect on operating costs, capital requirements to improve or upgrade energy sources, or convert facilities or equipment to other energy forms.

4. Formulate action and contingency plans to sustain operations in the event of energy curtailment or disruption.

Each of our facilities have developed such plans. At the Corporate level other programs are under consideration such as an LP standby equipment program, investigation of total energy concepts at certain facilities, and corporate fuel purchasing agreements.

5. Monitor the steps in the program.

Periodic progress reports are received from facilities and Divisions Management and Corporate Staff make periodic checks of the status of the action and contingency programs.

I do not mean to infer that the Emerson Electric Company has solved the energy situation at all its facilities or that we are so atop it that it is no longer a matter of concern. We are vitally concerned, but we are not fearful or awed. The energy situation is but another business condition which all successful managers, engineers and executives face and overcome in the normal course of their professional careers. At Emerson we believe we are informed, prepared, and confident that we can resolve situations as they occur.

No discourse on this topic would be complete without a look into the future. Mine has been easy to develop because it is substantially the same as I presented a year ago at a Corporate Seminar. I believe it is as applicable today as then, and will probably continue to be applicable for several years.

NATIONAL OUTLOOK

A. Consumption of energy will increase.
   1. Population Growth
   2. Increased mechanization
   3. Increased standard of living
B. Energy costs will increase
   1. Increased labor cost
   2. Fuels must come from more remote sources
   3. Investments will increase
   4. Increased demand
   5. Restrictions lifed on explorations
C. No new sources of energy are imminent.
   1. Geo. Thermal
   2. Nuclear
   3. Solar
   4. Direct conversion
   5. Hydrogen
   6. Coal gasification
   7. Shale oil
D. Ecologists and environmentalists are setting severe standards.
E. Utilities are pressing for higher rates
F. Customer resistance will stiffen
G. Curtailment or interruption of fuel supplies is imminent.
H. Intense publicity by politicians and lobbyists to influence public opinion.
I. Government regulations will be imposed.

Several items should be added to this.

X. Our Past National Energy Policy - to provide an abundance of inexpensive energy - will pass into history.

Y. This change presents opportunities - new products, new technology - for those who recognize them and are willing and able to act.

EMERSON'S OUTLOOK

A. Facility requirements to meet growth projections will continue to increase.
B. Cost of new facilities and expansions will continue to increase. Several items should be added to this.
   X. There are substantial opportunities to conserve energy within Emerson.
   Y. New facilities, equipment and processes should be designed to minimize energy consumption or other more abundant energy forms.

To Summarize,

Almost all ideas and proposals for energy conservations fall into three categories.

Reduce consumption

Reclaim unused energy

Change materials, processes, equipment, etc.

Conservation proposals should be tailored to a specific facility, considering

Product

Location

Basic energy form

Emerson's approach to Energy Conservation is

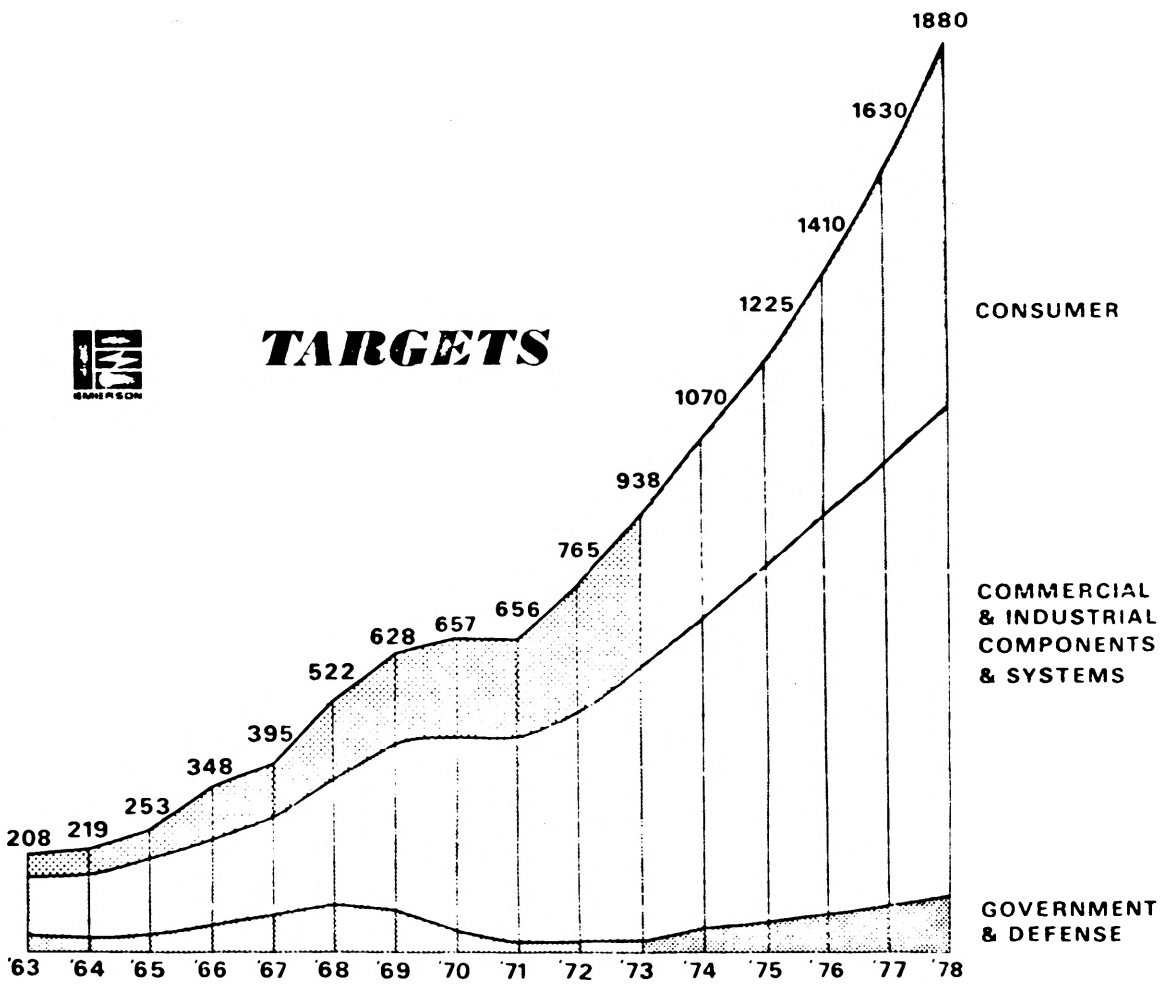
Management involvement

Data Collection

Date analysis and evaluation

Program management

Finally there are beneficial opportunities to be found in the present situation.



Slide I

Operating Results
1st Quarter - FY 1974

	Quarter Ended 12/31/73	1974 % Increase Over 1973 Restated
Sales	$ 243,118	18.3%
Earnings Before Income Taxes	39,735	12.0%
% To Sales	16.3%	
Net Earnings	20,265	13.0%
% To Sales	8.3%	
Net Earnings Per Common Share	.39	14.7%

Slide II

Uniroyal's Approach to Energy Management

J. C. Madigan
Director, Operations Analysis
Corporate Engineering
Uniroyal, Inc.
Middlebury, Conn.

ABSTRACT

Uniroyal makes selected consumer and industrial products including chemicals, plastics, and rubber articles in 90 plants worldwide. About 90% of raw materials are petroleum-based and about $40 million will be spent on energy in 1974.

Energy management includes centralized monitoring and feedback of usage per unit of production at all factories; energy audits; educational programs; suggestion systems; operational, maintenance, and capital investment programs. Specific items are detailed. Organization places responsibility on Divisional Coordinators backed by President and Divisional Vice Presidents, coached and assisted by Corporate Coordinator and Engineering Specialists. Results in 1973 were very encouraging.

INTRODUCTION

Energy management, while containing certain basic essentials in any company, will have parameters scaled to those of the enterprise itself. The tire business, by which you may know us best, brings to mind the heavy energy loads characteristic of rubber mixing, calendering, extruding, and curing operations. Perhaps less known is our involvement with the production of many polymers and chemicals, yarns and woven goods, coated fabrics, automobile and truck parts made of plastic and rubber, not to speak of golf balls, carpet underlay, footwear, protective clothing, and a wide range of industrial rubber goods such as hose, conveyor, and power transmission belting.. Throughout the 80 factories around the world included in our conservation program, large and small, there are common denominators and some that are not so common.

Of the 40 milliondollars worth of energy that we use, about 60% is in the form of electrical power, and the balance is distributed among various kinds of fuels -- natural gas, oil, coal and propane, in that order.

I will be talking here about the conservation of all forms of energy in our plants, but we all know that what we are really concerned with is the conservation of petroleum and natural gas. This is dear to our hearts for a very important reason, which is that a very large percentage of the raw stuff from which we make our products is based upon petroleum and natural gas. Think of synthetic rubber, plastics, carbon black, and chemicals, and you are thinking about Mother Nature's bequest of oil and gas which we are burning up at a frightening rate.

GENERAL

In recognition of this, Uniroyal has created a new corporate position concerned solely with the long range procurement and development of material and energy sources, including novel methods of recycling.

In still other ways, we contribute to conservation. For example, by making available and promoting the radial tire, we are helping to achieve a potential saving in motive power of up to 10%. Another example is in agriculture, where several of our chemical products are widely used to reduce the need for mowing, cultivating, pruning and other operations that consume fuel.

When the Company Chairman and President are committed to saving energy, as ours are, the job of a conservationist is a lot easier. We, as a company, were fortunate enough to have recognized the signs of dwindling supplies some years back. In 1970, our growing concern was in terms both of rising costs and potential production curtailments. To give you some ideal of why we were concerned, take a look at this prediction by our Purchasing Department on what we are facing. (Figure 1)

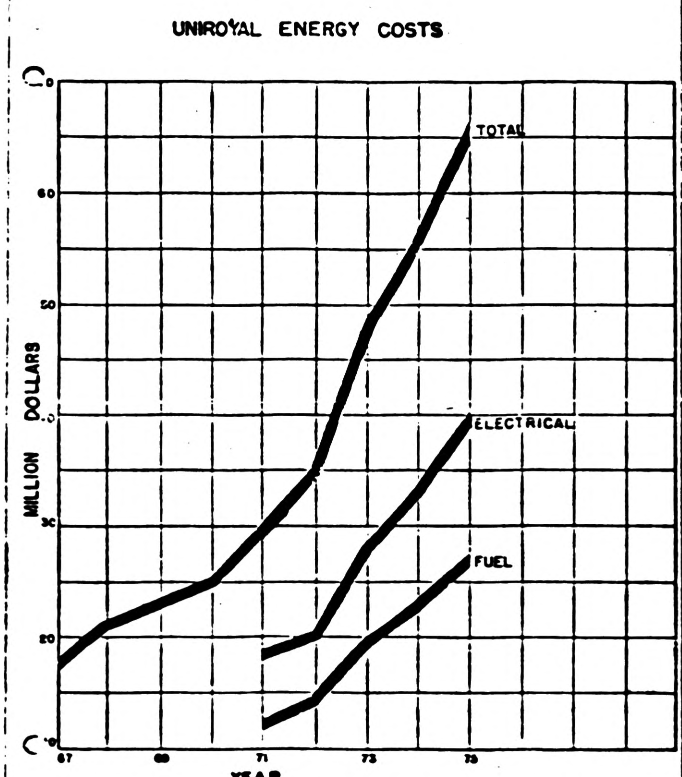


FIG. 1

EARLY ACTIVITIES

One of our early activities included a seminar for Divisional Utility Engineers in which a good many ideas on methods of conservation were proposed and detailed. Out of this grew a format for monitoring plant performance which we feel gives a good topside measure of how each one stands at any time and how much progress is being made. Recognizing that sales dollars and and fuel prices would be a fickle and delusive parameter, we set our primary monitoring factors on the solid footing of Btu and kwh per pound of production. Figure 2 illustrates the way in which we record and present the electrical data for our factories. Here you have the monthly and 12-month moving record of electrical load factor (a measure of how well the load is spread over the month) and power consumption per pound. This is a plant that normally operates 5 days, 3 shifts, and the load factor runs around 70%.

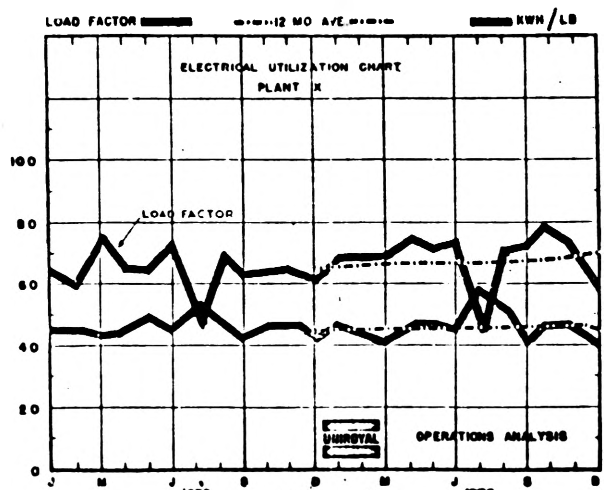


FIG. 2

Figure 3 shows the same data for another plant; in this case, one that normally runs 7 days, 3 shifts, and the load factor is over 80%.

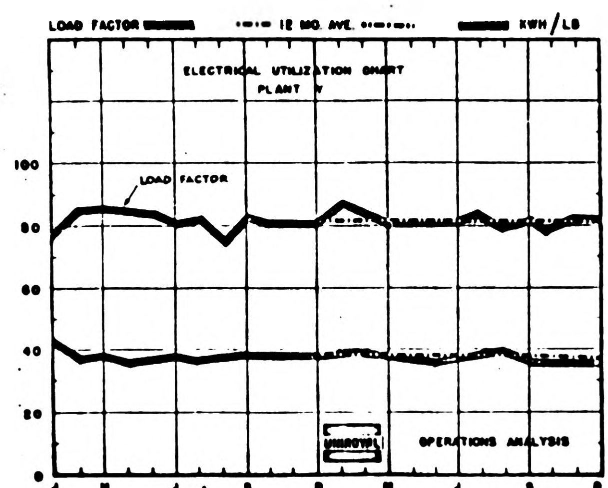


FIG. 3

On Figure 4 you can see a similar kind of record; but in this case, we are looking at this plant's boiler house operation and the way it uses the steam once it's out of the boiler house. The amount of steam you can get from a million Btu as contained in the fuel you are using should be upwards of 850, depending to some extent on what kind of fuel you are burning and the type of boilers in use. The amount of steam you use per per pound of product is the other half of the coin and can, of course, varies widely with the product.

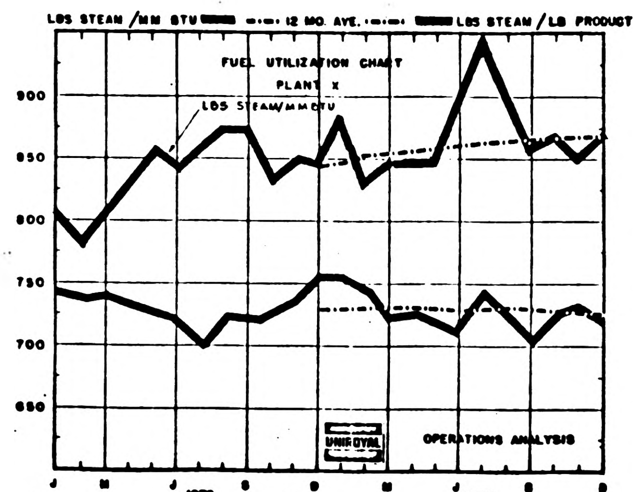


FIG. 4

Figure 5 shows the same thing for yet another plant.

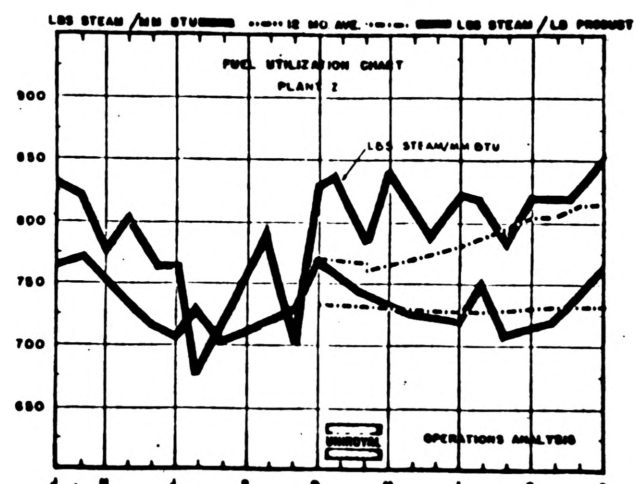


FIG. 5

Since the specific values will vary from one plant and product to another, we have omitted the actual usage per pound. The idea is to keep the load factor and efficiency up and usage falling. Believe me, everyone concerned is eyeballing these figures, and everyone is concerned, which leads to the question of organization.

It bears repeating that you get everyone concerned if the top man feels that way but that's not the end of the story -- it's only the beginning.

ORGANIZATION

Depending on the size of the organization, you have to decide the dimensions of the appropriate para-hierarchy. Quite obviously, a $1,000-a-year expenditure on energy, with a saving potential of, say 20%, or $200 doesn't warrant a team of experts. But since we are hoping to save somewhere around 20% of $40 million a year, we could afford to put some muscle against it. Figure 6 is an outline of our concept.

ORGANIZING FOR ENERGY CONSERVATION

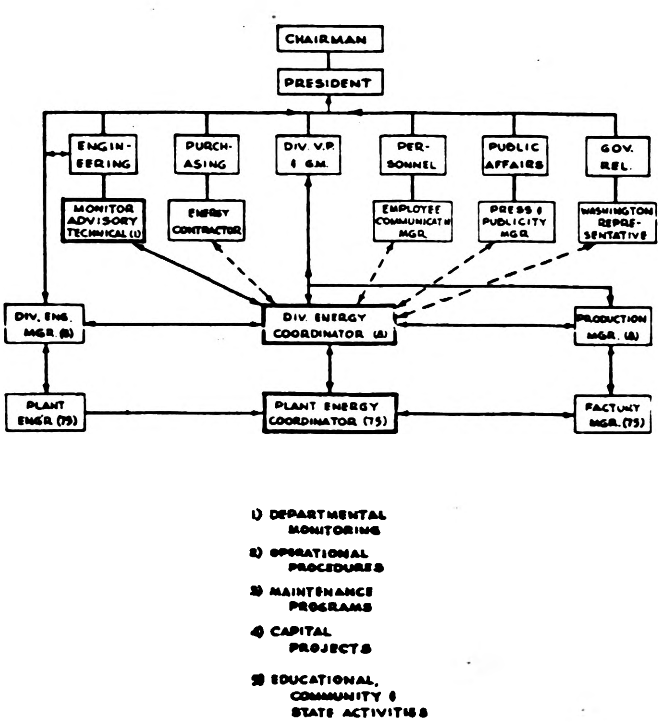


FIG. 6

I used the word "para-hierarchy" to emphasize a point. Whatever is "everyone's job" can easily diminish to "nobody's job." Although the Chairman, the President, the Engineering Vice President, and Divisional General Managers, and Production, Engineering, and Factory Managers are all involved and interested in the conservation effort, there has to be a more specific structure to assure continuity, completeness of coverage, and feedback. The illustration emphasizes this point. There is in each of the eight Divisions an Energy Coordinator whose specific duties include monitoring, procedures, programs, projects, and all the other energy-related activities within his Division. They have an average of ten plants to look after, and they, in turn, have someone in each plant whom they can hold responsible at the local level.

It is the Divisional Coordinator that we in Corporate Engineering hold responsible for the results we are monitoring, and it is to them that we direct the counsel and ideas that our corporate staff can provide. Quite naturally, the management looks to Corporate Engineering for overall coordination, monitoring, and feedback.

FACTORY AUDITS

Early in the course of events, we decided that the keystone of our program would be an audit of each plant, and we set out to do this, starting with the largest plants in each Division. In a few cases, we enlisted the aid of a consulting service which had made a specialty of energy audits and conservation. Figure 7 outlines the important features of such an audit.

ENERGY AUDIT

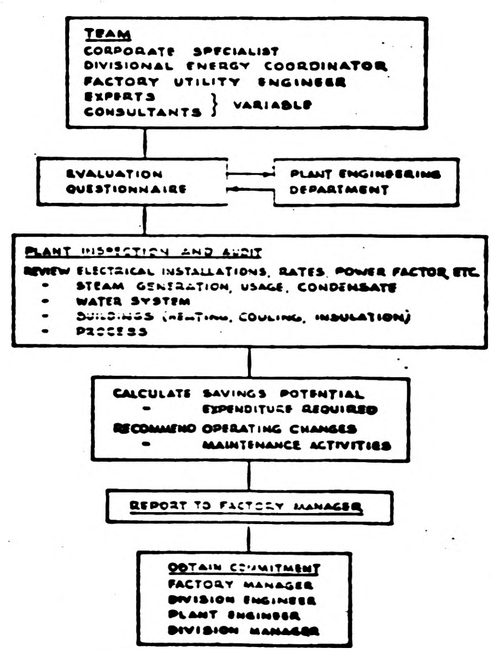


FIG. 7

As expected, these audits revealed many opportunities for conservation. In general, they can be grouped under operation, mainten-ance, process, and equipment revision and fuel substitutions. We have listed the most significant under the first three headings.

OPERATIONS

The ones you see on Figure 8, in many cases, are things that can be corrected without spending any money other than the educational effort needed to tell people the right way to run the equipment and motivate them to do it. We should be doing this anyway, and it's often a matter of redefining our our own priorities as supervisors.

The factory is not the only physical unit to look at. In our new Corporate Headquarters, we found that by revising thermostat settings and the quantity of recirculated air, we reduced our fuel oil usage in gallons by 40% over the previous season, after adjustment for "degree days."

SAVING UTILITIES THROUGH OPERATION

I WATER
- A. TEMPERATURE SPECIFICATIONS
- B. RECIRCULATION RATIOS
- C. MISAPPLICATION

II BOILERS & STEAM
- A. MINIMUM EXCESS OXYGEN
- B. BURNER ADJUSTMENTS
- C. UNIFORM STEAM LOADS
- D. EXCESSIVE BLOWDOWN
- E. MISAPPLICATION & EXCESS USAGE
- F. DETECTION OF MALFUNCTION, TRAPS, EJECTORS

III COMPRESSED AIR
- A. EXCESS OR WASTEFUL USAGE
- B. OFF LINE USAGE
- C. IMPROPER SIZED COMPRESSORS
- D. COMPRESSOR OPERATING CONDITIONS

IV ELECTRICAL
- A. INEFFICIENT SCHEDULING - LOW LOAD FACTOR
- B. POOR OPERATION - HIGH DEMAND PEAKS
- C. POOR POWER FACTOR OPERATION
- D. MISAPPLICATIONS
- E. MOTORS LARGER THAN REQUIRED

V HEATING SYSTEMS
- A. LESS MAKE-UP AND EXHAUST AIR
- B. TEMPERATURE REDUCTION - HEAT & HOT WATER

FIG. 8

MAINTENANCE

Figure 9 puts the spotlight on maintenance. Here again, priorities always dictate the work that gets done. Today, with the kind of cost escalation depicted on our first slide, it's a lot easier to back up the kind of maintenance expenditure needed to keep these items in proper shape. Again, education and training of people is important.

To supplement our own training on these subjects, we found that there are self-contained courses available at low cost and suitable for use without elaborate preparations.

ENERGY SAVINGS CHECK LIST

MAINTENANCE

I STEAM TRAPS
- A. INSPECTION PROGRAM
- B. PROPER SIZES & TYPES
- C. ELIMINATION OF BY-PASSES

II STEAM LEAKS
- A. REPLACE FLANGE GASKETS
- B. CHECK UNIONS - JOINTS - ELBOWS - TEES
- C. CHECK STEAM-CONSUMING EQUIPMENT
  1. TRACERS, PIPING, HOSES, VALVES

III INSULATION
- A. CONDITION - WORN, DAMAGED, NONE
- B. THICKNESS - HEAT LOSS vs. FUEL COST
- C. APPLICATION - STEAM, HOT WATER, REFRIGERATION PIPES
- D. BUILDING - ROOF, WALLS
- E. WINDOWS - WEATHER STRIPPING

IV STEAM JET EJECTORS
- A. PROPER SIZE ORIFICE
- B. WEAR CAUSED BY WET STEAM
- C. LEAKS IN VACUUM SYSTEM
- D. CORROSION

V COMPRESSED AIR
- A. LEAKS
- B. COMPRESSOR LUBRICATION & CARE

FIG. 9

CAPITAL PROJECTS

The next category is that of capital improvements. Many of these kinds of savings are fairly obvious, but were assigned low priority in the past. Just glance at Figure 10 for a condensed list of things we are doing. No surprises, just sound engineering -- with the spotlight focused on a corner of the business that had been passed up for years because of higher priorities.

ENERGY SAVINGS CHECK LIST

PROCESS CHANGES & CAPITAL IMPROVEMENTS

I. EXAMPLES
- A. PROCESS OVEN
  1. INCREASE IN % AIR RECIRCULATED
  2. CHANGE IN PROCESS SEQUENCE
  3. ELIMINATION OF ONE OPERATION
- B. MAJOR STEAM LINE INSULATION
  1. INVESTMENT $120,000
  2. ANNUAL SAVINGS $100,000
- C. CONDENSATE RETURN SYSTEM
  1. RECOVERY OF HEAT IN CONDENSATE
  2. LESS TREATMENT REQUIRED
  3. REDUCTION IN MAKE-UP WATER & TREATMENT
  4. INVESTMENT $45,000
  5. ANNUAL SAVINGS $37,500
- D. CONTINUOUS BOILER STACK MONITOR
  1. CONTROL OF COMBUSTION AIR
  2. INVESTMENT $6,000
  3. ANNUAL SAVINGS $10,800
- E. RECOVER FUEL OIL HEATING CONDENSATE
  1. INVESTMENT $2,000
  2. ANNUAL SAVINGS $8,250
- F. POWER FACTOR CORRECTIONS
- G. STEAM TURBINES FOR PRESSURE REDUCTION
- H. HEAT INTERCHANGE
  1. AIR/WATER
  2. AIR/AIR
  3. WATER/WATER
  4. STEAM/AIR
  5. STEAM/WATER

FIG. 10

COMMUNICATIONS

For a program like this to be successful, not only the engineers need to be involved. One of the obvious dis-economies of scale is the communications barrier, whose height seems to increase as the square of the size of any endeavor. Our Employee Communications people have recognized this, and they keep up a constant flow of material for use in factory newspapers, bulletin boards, etc.

Additionally, our factories utilize the suggestion system, local newspaper and radio publicity, various kinds of contests, and similar activities to create awareness. When people realize the continuity of their jobs is at stake, they will rise to the occasion.

RESULTS

Our conservation program has paid off so far. I mentioned that we are shooting for an overall improvement, to be accomplished in about three years, of a 20% reduction in energy consumption per unit of output. In 1973 we were right on target, with a 7% reduction over 1972.

SUMMARY

In summary, the essential elements of our program have been:

Involvement of top management.

Designation of Divisional Coordinators

Factory audits of operational, maintenance, and process opportunities.

Goals and commitments at factory level.

Communication to create awareness.

Education of operators and maintenance personnel.

A monitoring procedure with feedback.

We have made significant progress and fully anticipate that we will continue to do so.

ENERGY CONSERVATION: CONSTRUCTIVE BUT NO CURE

N. V. Poer

General Motors Corporation
Detroit, Michigan

Let me share with you a quotation from a report issued by the Chase Manhattan Bank while the Arab oil embargo was still in effect. "Reportedly, the annual cost of a gasoline rationing program would amount to $1.4 billion. Based upon past results, if that much money was devoted to an exploratory effort, it would be potentially capable of discovering more than 2 billion barrels of petroleum. That amount of petroleum would be equal to 19 percent more than all the gasoline consumed in privately owned automobiles in 1973."

While the threat of rationing has disappeared with an end to the oil boycott, that quote is still valuable in assessing America's changing energy supply picture. It is valuable because it points out very vividly the two fundamentally different ways in which we can respond to that change.

One way of responding is simply to spread the scarcity around. Before the embargo was lifted, many people were demanding that this be done with formal rationing programs--even though experience has shown time and again that such efforts are neither successful nor equitable despite their heavy cost.

A much more logical response -- and the only one that makes any sense for this nation and its people -- is to set out immediately to increase the available supply of all kinds of energy, and manage its use more effectively.

At the outset, then, let me define the way I'm going to use a key term. Conservation is the efficient and effective use of energy -- the elimination of waste and the best end-use in terms of resource availability. But this concept should not be confused with reductions in living standards or changed life styles. For example, reduced highway speed limits, filling stations that are closed at night and on weekends, 68 degree thermostats, winter Daylight Savings Time, and no use of air conditioning in summertime are really <u>energy austerity</u>, and should not be confused with legitimate conservation.

Don't get me wrong: conservation is very important. It is a way we can help overcome the shortages that are still with us, and for the future, the more prudent use of energy must remain a priority for as far ahead as we can see. Indeed, it seems to me that one beneficial aspect of what has been called "the winter of our discontent" is that it brought home forcefully to us the need to use all our finite natural resources more wisely, including energy. We need a continuing plan for energy conservation to help us put an end to energy austerity.

The various approaches to conservation that are being described at this conference are all commendable and worthy of our support, I'm sure. No doubt that all of us -- individual and corporation alike -- can do a more efficient job of managing the energy resources that we must use.

At General Motors, we're very proud of what we have already accomplished with our Corporation-wide conservation efforts. Our program builds upon the historic concern over holding down fuel and utility costs which has made industry one of the most efficient users of energy. Now, however, we are finding that we can do far more than we have ever done before, and to reflect the changing times and changing priorities at GM, we now measure savings in Btus as well as dollars.

But, as important and laudable as conservation is, it cannot provide the energy that our nation needs for the future. Trying to save our way into adequate future energy is comparable to trying to ensure all of the food our families will need next year solely by dieting that much harder now.

It won't work. And any nation or family that tries it will wind up in a seriously weakened position. Yet, we frequently hear that this is what we must do -- retrench and retreat, give up some of the good things in life that we've worked so hard to attain, for ourselves and our children. Those who see conservation as the only answer to our dilemma say that we must now begin to change the way that we live -- and change it drastically.

I say we don't. We won't have to sacrifice our way of life and our high standard of living -- and deny it forever to those among us who have yet to achieve it -- if we adopt as national policy the idea that we should expand all available energy sources -- conventional and exotic, those that are familiar to us and those that are still to be discovered.

If we decide on a course other than this, our social and economic progress and individual freedom of choice will be endangered. Our children and our grandchildren will face lives that are not as good as ours have been. They won't have as much mobility, comfort, convenience or individual freedom as we have had; they won't have as much opportunity either.

Those who say that America must reduce its energy use point an accusing finger at the fact that with just six percent of the world's population, America uses almost one-third of the energy that is consumed. They cite this as proof that we are indeed a nation of wastrels. But they overlook one important point: by using that much energy, one-sixteenth of the world's people is able to produce one-third of the world's goods.

U. S. productivity is based on the use of energy-driven machines, and it is the foundation which supports a standard of living that is the highest in the world. This productivity is what enables an American to purchase a car with less than half the work of a

British laborer; a TV set with two-thirds less work than a Frenchman; or a dozen oranges for just one-seventh the time that it takes a Japanese to earn them.

To conserve energy -- use it wisely -- is one thing. To hold it dear -- as something to be hoarded, protected and preserved rather than put to work for mankind's benefit -- is quite another.

If this nation runs seriously short of fuel in the years ahead -- whether from a purposeful course of reducing demand or by default through failure to increase the supply -- our productivity and the benefits that it bestows on us will be lost. Then we will have neither the abundance of goods that we now enjoy nor the affluence that enables most of us to afford them, and a plaintive cry will go up, "why is this happening to us?"

What is happening to us now is that we have just begun to feel the initial cumulative effects of an assortment of short-sighted or wrong-minded energy policies in the past -- or the lack of any policies at all. If we do not replace those policies and non-policies with a comprehensive, cohesive national goal of increasing the supplies of energy, the shortages inevitably will get worse, no matter how efficiently we practice legitimate conservation. We should begin by the deregulation of natural gas prices in interstate markets. As long as a single energy form is regulated, other forms will also be affected. We have seen that in the past. The imposition of unrealistically low natural gas prices has tended to keep down the price -- and the supply -- of not only natural gas, but domestic petroleum and coal as well.

Lower prices meant more energy was used. The economic incentive to use it efficiently and effectively was missing. Natural gas, for example, was often used for inferior purposes, such as for boiler fuel in raising steam or in generating electricity. Low prices also dampened incentives to find new supplies -- not only of natural gas, but of other forms of energy, because they have to compete with low gas prices in the marketplace.

Deregulation would undoubtedly mean higher gas prices for many people. And none of us want to pay higher prices -- if that is all there is to it. But it is rarely that simple. In the case of natural gas, arbitrarily imposed low prices have caused the current shortage of this clean, premium fuel, and also contributed to scarcity of other domestic fossil fuels.

Higher prices will discourage the wasteful or inefficient use of fuel, but just as importantly -- maybe more so -- they will provide the incentives that are necessary to finding and developing new and additional reserves.

General Motors strongly supports the deregulation of natural gas, especially new gas. We believe substantial new quantities will become available if the current average controlled price of 24 1/2 cents per 1000 cubic feet in interstate markets is allowed to rise in response to market demands. To put that 24 1/2 cents in perspective, I should note that some gas has been sold in intra-state markets lately -- markets that are not controlled -- for as much as $1.25/Mcf.

Just as natural gas regulation has disrupted and distorted the workings of the marketplace in the past, the federal mandatory fuel allocation program is now doing the same thing.

As a result of the allocation program, limits are still being placed on the quantities of all products that can be sold, although there is now no real reason for them.

The Federal Energy Office, no matter how well-intentioned or hard working, already has proven that it cannot distribute the available supplies of fuel as effectively as private enterprise, responding to a free market.

For example, heating oil is now in oversupply, even to the point of taking up storage space that is needed for gasoline. During this winter, distillate inventories were allowed to build up to 50 million barrels above last year's level, although demand was down substantially because of warmer weather and conservation efforts. This created unnecessarily severe shortages of gasoline, with serious results that spread throughout our economy.

In line with our belief that we should permit the market to work freely, the FEO should now turn the distribution of fuel supplies back to those who know the task best. The FEO could then devote its efforts to coordinating the proper government role -- encouraging and supporting efforts to increase our energy supply.

In addition to the decontrol of all energy and its prices, Congress should approve a strong energy facility siting bill so that refineries, power plants, deep water ports and the like will no longer be delayed by endless litigation. Priority items should also include a major expansion in the leasing of mineral rights on the Outer Continental Shelf and in the public domain; a relaxation and delay in sulfur emissions standards that are applicable to stationary sources -- until necessary equipment for its removal is commercially available; a continuing shift of electrical utilities and power plants from oil and gas to coal as fuel; approval of a workable strip mining law to increase coal production; and stepped up research into potentially promising new energy sources, including shale oil, nuclear fusion, solar energy and hydrogen fuels. Stepped up efforts and research into the recovery of energy from waste are also needed.

New sources of energy -- of almost any kind -- will be expensive to bring to the market; I've no doubts about that. A return to freely operating markets will provide adequate incentives for those who must undertake the necessary exploration, research and development. But in addition to adequate incentives to act, we must assure more freedom to act.

To provide this freedom, we -- as a nation -- must reassess the controls and limitations that have been imposed in recent years in the name of protecting the environment.

Protecting the environment is a legitimate concern, and I'm not suggesting that we give up the gains that we have made in controlling pollution of all kinds. But we must strike a better balance between our need to protect the environment and our need for adequate energy. Many environmental regulations are arbitrary and overly stringent. They were adopted at a time when energy supplies were of little or no concern and the fervor for ecological improvements was at its peak.

Now, we must enter energy into the equation, recognizing that it, too, is a legitimate need and that more rational trade-offs can be made -- trade-offs to provide access to more energy but still to protect the nation's water and land and air from unnecessary despoilment.

As I indicated, we especially need to reassess the restrictions that have been placed on the production and use of coal. America's coal reserves are among the most abundant on earth. They could meet all our energy needs for several hundred years -- if we just put them to work.

First of all, we need to re-examine the scientific data on which ambient air standards have been based. A thorough investigation is needed to determine if sulfur dioxide is the potential health problem it generally was thought to be. An increasing number of experts believe that it is not. They believe those standards are more strict than necessary to protect the health and well-being of most of our citizens -- just as most people, I think, now agree that the auto emission requirements are more strict than they need be for most parts of the country.

If we return to the greater use of coal, particularly to generate steam and turn electrical generators, scarce petroleum would be freed for higher value uses. Transportation should have first call on petroleum because there is no alternative fuel available at this time, and natural gas should get priority for use in heating homes for use as petrochemical feedstocks and in specialized process use in industry.

Industry, traditionally, has had lower per-unit utility rates than homeowners or smaller users. This is the way it should be, because it obviously costs less to serve one large user than it does many smaller customers spread over a wide area.

But now this traditional and soundly based utility rate structure is being challenged, and the challenges include both state and federal government agencies -- agencies that seek to reduce legitimate demand growth, although they frequently call it waste.

Because of increasing energy costs and shortages, new schemes have emerged which would force industry to pay a major portion of rate increase to provide the higher revenues required by the utilities.

Higher energy costs for industry are not the bone of contention. Industry recognizes that higher utility rates are necessary. What we oppose are proposed flattened, inverted or peak-load pricing rates which would force industry to subsidize other utility customers and in effect pay more than a fair share for utility services.

We are participating with other industrial firms in opposition to such proposals -- including two here in Missouri. The adoption of such proposals would make industry in the affected area more non-competitive with localities that retained traditional pricing policies. The ramifications of such decisions are broader and more wide-spread than you might imagine. States that penalize industry like that will likely drive it elsewhere.

This is just one of many problem areas facing the nation in what is admittedly a difficult time. But it points up the fact that the fundamental question that we face may not be so obvious to all our citizens.

This nation still has abundant energy resources -- the greatest total resources of any single nation on the globe. Some authorities state that we have enough coal -- proven and potential -- to last 5,300 years at the rate that we used in 1972. America is also blessed with a potential 485-year supply of petroleum -- plus an additional 4,300 years if you consider the total possibilities of oil shale. Despite our mismanagement in the past, we still have enough potential natural gas reserves to last us 290 years at present rates. We must recognize, though, that while our remaining resource base is still large, a good portion of it will remain unrecoverable -- even with improving technology and economic incentives.

Still, the question we face is not prospective energy sources, neither conventional nor new and exotic for that day in the future -- and you can see that it can be a long way off -- when U. S. fossil fuels are finally depleted. The question is not whether this nation is capable of achieving self-sufficiency. Nor is it whether we can use energy more efficiently.

The central question is whether this nation -- our people -- can make the right political and economic decisions that will permit technology and free enterprise to do the job that must be done.

Just as expedient politics and faulty economics are the root of our present troubles, rational political decisions and sound economic policies show us the way out.

I urge all of you -- when you return to your respective homes -- to take a more positive and active role in seeing that the proper decisions and far-sighted policies are adopted -- that America does not give up its leadership in the world and prosperity for its people by default. Increasing our energy supply is the only way to ensure that leadership and that prosperity -- for now and in the future.

Thank you very much for the opportunity to share with you General Motors view on a fundamental issue facing this nation.

DEVELOPMENT OF INDUSTRIAL ENERGY MANAGEMENT PROGRAMS

Michael C. Noland

Midwest Research Institute
Kansas City, Missouri

Energy management is a term which has only recently been entered in the business management lexicon. Until recently business managers, even the most successful ones, devoted only casual thought to the need to manage their use of fuels and electricity. Energy was cheap and plentiful. Economic sense dictated that if labor could be replaced by more energy-intense processes or equipment, the smart manager did so. Local and national policy, industrial process design, consumer habits--all these and more encouraged massive energy consumption.

But commerce and industry in the United States--indeed throughout the world--has entered a new era of energy economics. The demand for energy in its several forms has begun to seriously outstrip man's ability to produce it. Nowhere is this more evident than in the U.S. where our prodigious energy appetite has, in a matter of months, overtaken and seriously exceeded the domestic production capacity of our energy industries. The result has been rapidly escalating energy costs and, perhaps even more important, the threat of crippling reductions of the amount of energy available to all sectors of the economy. Suddenly energy economics and energy security have become crucial issues in business management. Several organizations with sufficient managerial and technical resources have established energy management programs. Others have gone outside the company for counsel and assistance in developing energy conservation and management strategies. But the majority of commercial and industrial enterprises in the U.S. have not yet decided how to approach energy supply problems. It is in this climate that the science/art of energy management is born.

Energy management is simply the application of modern business management practice to the purchase, distribution, and utilization of fuels and electricity. In this context, it does not differ significantly in concept from the application of well-established management principles to other elements of a business operation, such as administration, purchasing, production, marketing, or finance. The factor which sets energy management apart from these other management tasks is that it deals with a commodity which, although crucial to commercial and industrial activities, has been almost completely neglected in the design of the management systems and physical facilities which constitute our economy.

An energy management program can range in complexity from an energy conservation effort coupled with careful accounting of energy costs to sophisticated, computer-based programs which continuously monitor energy consumption and include upgrading of energy-inefficient processes, development of advantageous contracts with energy suppliers, employee incentive programs, and numerous other concepts. But to be effective, whatever the complexity, every energy management program must be based on a sound understanding of the energy supply demand characteristics of the particular operation for which the program is designed.

It is a common mistake to regard an energy management program as merely an organized approach to energy conservation in an office or plant. Whereas energy conservation is certainly a central element in any energy management program, it is by no means the only feature. The objectives of an energy management program are to: (1) minimize energy costs in a manner consistent with the productivity and profitability goals of the operations; and (2) decrease the vulnerability of the operation to energy shortages. Energy conservation can make important contributions toward both objectives. But a comprehensive energy management program also includes many other items.

Elements of an Energy Management Strategy

Energy management can encompass the same wide range of complexities as more familiar business management concepts. And, of course, it can utilize many of the same management tools--systems management, operations research, value engineering, cost/benefit analysis, technological forecasting, and others. The response of many businesses to the on-set of an energy short economy has been the development of energy management concepts, or more accurately, the organization of existing contemporary management techniques into a coherent system designed to manage energy in business operations.

Listed below are several steps which constitute a simplified strategy for energy management. The strategy consists of 14 steps which can be carried out to organize, implement, and evaluate an energy management program. Like all management strategies, it is not unique. Numerous variations are possible.

1. Designate a corporate team to investigate energy problems and formulate an energy management policy for each facility. The individuals responsible for energy management at each major facility should serve on this team. It should also have representation from the corporate management and planning staff and the engineering department. It should be vested with authority adequate to investigate prevailing energy supply and demand situations and to implement policy recommendations. The tasks of the energy policy team should be assigned a priority consistent with the current or potential importance of energy problems in the company operation. The team should inventory talents within the firm which could contribute to the analysis and utilize those talents.

As discussed in more detail later, two factors are very important in developing the energy management organization: (1) It should involve a serious and continuing commitment on the part of top management; and (2) one individual should be made ultimately responsible for the success or failure of the program.

2. The energy policy team should specify the need for such a policy and the objectives of the team's efforts. It should examine available corporate energy-related data and prepare a report which outlines the overall energy status of the company. This should serve as baseline information.

3. The need for expert counsel or assistance from outside the company should be determined early in the planning effort. If such assistance is advisable, it should be obtained sufficiently early to contribute to the project planning tasks.

4. A thorough inventory of energy supply and use throughout the firm should be developed. In most cases,

this task will require considerable effort. It should result in a detailed description of how energy is obtained and used in each facility, with information down to the level of specific processes and equipment. It should catalog energy suppliers and tabulate historical data concerning energy supply and price trends. Fuel and energy cost data should be compiled as a basis for future monitoring of the cost impact of energy actions. An inventory of fuel storage capabilities and back-up fuel supplies should be included. This effort should generate a data base for energy policy development.

The key ingredient of this step is the energy audit, a crucial part of the total energy management effort. Energy audits are discussed in more detail later.

5. One member of the team or a consultant should be assigned the task of analyzing regional energy supply, distribution, and consumption characteristics. The objective should be to identify trends which will affect the availability of fuels and energy to the company, such as:

. consumption trends of other firms, industries, or economic sectors which could compete for the same fuel supplies,

. status of the company in fuel allocation programs,

. national issues which impact on the availability of fuels or the distribution of fuels to different regions (e.g., importing crude oil),

. economic trends of the region which could affect energy availability, and

. environmental regulations affecting fuel use.

6. An analysis of energy and fuel curtailments should be conducted. This should consist of case history evaluation of past fuel shortages and power outages with the view toward identifying predictors for such events. For example, have natural gas curtailments been preceded by consistent weather patterns as characterized in terms of degree-days? Assistance should be solicited from energy suppliers in this task.

7. Systematic "energy inspections" of all facilities should be conducted. These are intended to identify specific areas of energy inefficiency and potential for energy conservation. The inspections should be preceded by the development of checklists to help the inspector identify energy-sensitive areas. Each firm, or at least each industry, will probably find it necessary to develop custom-fitted checklists which recognize particular energy use characteristics of the industry. Inspectors should try to spot wasteful practices. Often a list of methods to save energy can help identify areas where wasteful practices prevail. For example, the knowledge that automatic controls can be used to increase combustion efficiency keeps the inspector alert for poor combustion control. The energy inspection should also serve to find operations where loss of energy would be critical, identify processes where back-up fuels could be used, and, in general, develop a comprehensive picture of the energy efficiency of the operating facilities. The inspection should include office, warehouse, and other facilities in addition to the process or manufacturing plants. An inspection report should be filed for each site.

8. An examination should be made of such items as work and production schedules, vehicle fleet operation, staff travel, and other activities which constitute areas for potential energy savings. Recommendations should be developed.

9. A review of new technology related to the principal equipment or processes used by the company should be carried out. The objective should be to identify technical improvements which can upgrade energy efficiency. The results should be correlated with the output of Steps 4 and 7.

10. Maintenance and equipment replacement schedules should be examined to determine their impact on energy efficiency. Recommendations should be made.

11. A study of the tangible and intangible costs associated with fuel or power shortages should be made. This should include the loss of production and service, the costs of plant shutdown, the risk of customer dissatisfaction, factors related to labor agreements, long-term impact on growth, and numerous other considerations. The objective of this analysis is to develop guidelines which, with the cost data from Step 4, can be used to evaluate the cost-effectiveness of energy actions.

12. The energy project team should utilize the output of the steps listed above to develop recommendations for energy-related actions. The recommendations should be classified as directed at energy economy or energy security. This is obviously a crucial task, and the effectiveness with which it is carried out depends on the thoroughness of the preceding efforts. The project team should now have a comprehensive understanding of the role energy plays in the company, the areas where energy savings can be achieved, the actions necessary to achieve those savings, the cost benefits of the savings, the areas in which the energy security of a plant can be reinforced, the problems encountered in obtaining fuels and energy, and many other items. Formulation of the recommendations should draw upon as many elements of company operation as possible. And an important part of this task is to develop methods by which the recommendations can be implemented. A formal report should be prepared which summarizes the project activities, compiles company energy data, and presents the recommendations and the implementation strategies. The latter two items--the recommendations and implementation strategies--should be presented as a series of recommended corporate energy management policies. The recommendations should include methodology for the continued evaluation of the effectiveness of the policies and the modification of the policies to improve effectiveness.

13. Develop an energy emergency plan which outlines steps to be taken for specified energy situations in each facility. For example, specify the procedures to be followed in the event of a natural gas curtailment, or a curtailment followed by depletion of standby fuel. Plans should include both the physical aspects of operation and such items as work and production schedules.

14. Develop an employee energy conservation education program directed at practices and procedures while on the job. Include an incentive system for the suggestion and implementation of energy saving actions. Program might also include means of saving energy at home and on the highway.

Organizing the Energy Management Effort

There are several factors which impact directly on the eventual success of an energy management program.

But none is as important as the commitment made to the effort by top management, including the chief executive. This commitment must consist of talent, resources, responsibility, and authority. Energy management, like other management disciplines, is concerned with the future. True, that future might be as near at hand as the next day or hour, but no management decision ever changed the course of events which had already occurred. The organization of an energy management program, therefore, involves two central tasks: (1) develop a plan; and (2) create an organizational structure specifically designed to carry out the plan. The distinction between these two tasks is often impossible to detect. Is a plan necessary to design an organization or is the organization necessary to devise a plan? The process is to some extent iterative. Some elements of the organization must exist to develop the plan. And the plan can lead to an organization much different than the original.

In its most general context, planning is the development of a desired future strategy and the design of effective methodology for implementing that strategy. Developing the plan for an energy management program involves such factors as: (1) organizing the program; (2) developing energy management information; (3) conducting energy audits; (4) analyzing operations with an energy perspective; (5) implementing the strategy; (6) evaluating progress; and (7) reporting and publicizing the results.

The development of an effective organization for energy management is a major undertaking in project organization. It involves organization within the corporate management structure which, unlike task force projects, touches on all functions of the business. Several items are important:

Top management commitment to the need for energy management is essential. No part of the company can be disinterested in the goals and execution of the program. But this is particularly true of top management, including the chief executive. The most effective programs are often initiated by top-level managers who take the first steps in organizing the program and make their commitment to its success well known throughout the company. Even after an organization has been developed they make their continued interest obvious. Their commitment must include staff, resources, responsibility, and authority. It must be very clear that the company has been firmly committed to a course of improved energy management.

The need to conserve energy in industrial operations is now recognized at all levels in most companies. Therefore, the initial stimulus for an energy management program might come from any one of several points. Many of the early successes, however, originated in the board rooms. The corporate executives and board members usually have wide exposure to the problems being experienced or anticipated by other companies, including the energy industry. They can assess the severity of possible energy-related problems and can interpret the impact of energy-induced changes in the economy of the profit picture of their own company. Usually these preliminary insights show that either expenses could be reduced or significant future adverse effects could be avoided if energy management could be markedly improved. Further study shows that energy consumption has not been considered in much detail in operation management strategies. Frequently, top management is the first to detect conditions outside the company which can have a future deleterious impact on productivity and profits. Middle management and operating staff are usually immersed in day-to-day operating problems to such a degree that they do not foresee long-range problems. Two years ago fuel costs and shortages were long-range problems. Now they are day-to-day events. And more than ever they require the attention of top management.

This commitment might start with top executives identifying the problems and initiating the program. Or it might involve selling the need for the program to top management. The former is better. But the program stands little chance of succeeding without real, substantial, visible, sustained support by top management.

A specific individual must be charged with responsibility for the overall success of the program. He (she) must be empowered to develop plans, make staff assignments, allocate resources, and implement energy conservation measures. He should have direct access to top corporate management and should receive quick decisions when he presents a program or program element for approval. His appointment should be made with internal fanfare as further indication of executive commitment to the energy management program. His responsibilities and authority should be defined (although this definition might have to be updated as the program develops), and his authority should be clearly specified to the other staff with whom he will work to obtain energy savings.

This position might be designated, for example, Corporate Energy Coordinator. The appointee might be made responsible for the entire corporate energy budget, and his performance would be measured in terms of energy economics and energy security. One such measure might be a specified reduction in energy consumption in some process or facility. Or it might be a reduction in energy consumption per unit output... or number of months without an energy-related loss of production.

The investment which can be made in the various staff assignments to the energy management program depends, of course, on the potential return. Although energy stakes are high and becoming higher, not all organizations can afford a full-time appointee in the top position. It's desirable, however, because the magnitude of the task certainly justifies that type of effort. And a rather pragmatic approach must be taken in evaluating the return on investment. Every effort should be made to assign a person full-time to the most responsible position until such time as the optimum involvement can be determined. Any company with annual energy expenses of about $250,000 or more (and that's small by today's standards) can probably justify the equivalent of one or more full-time assignments to an energy management effort.

The leadership position should be filled by someone with a broad knowledge of all aspects of the company's operation. He must have easy access to all elements of the organization and be the type of person who refuses to be made merely a figurehead.

Formal energy management groups should be designated to implement the program in various segments of the company. The people who carry out the day-to-day functions of the business play a key role in program achievement. Plant foremen, shop stewards, union heads, line managers--these and others should be called upon to contribute to the various tasks. The extent of their involvement depends, of course, on the size of the company and the magnitude of the energy management effort. An energy program manager might be designated for each plant in the corporation, or each operating division, or each production operation. These managers, working with the aforementioned corporate energy coordinator, would designate an energy control team for their plant or division or production operation. This team, which would include production workers, maintenance personnel, etc., in addition to supervisory personnel, would be assigned the tasks of the program (such as energy inspections and the other tasks to be discussed later). The team members would periodically carry out these assignments and report the results to the cognizant energy program manager. Again, the number of people involved in the energy control team and the extent of their individual involvement, depends on the magnitude, or potential magnitude, of the energy problem in each company. Usually the position of energy program managers for a plant or production operation is a part-time assignment to someone who has other duties. Involvement of the energy control team is also on a part-time basis. In any case, no assignment is justified unless it can be justified on the basis of cost, accounting loss of production due to energy outages as a cost factor.

Organizational links should be established with the more traditional departmental functions of the company--public relations, personnel, staff development, engineering, sales, marketing, and others. The public relations department or whatever department is responsible for internal communications is important because of the need to keep the goals and benefits of the program in the minds of all employees. The internal employee newsletter is an effective organ for this purpose. Or a special bulletin on energy conservation of energy management might be appropriate. Employee training programs are well-suited as a forum for energy conservation education.

. Assistance from outside the company should be secured when appropriate. There are several highly qualified consultant services available concerning energy conservation and management. Often these firms can be more cost effective in carrying out some program functions than can a company's own staff. And one of the tasks for which they can be most effective is in the development, organization, and initial implementation of your energy management program for subsequent operation by the designated members of the company staff. Training members of the energy program team can also be an appropriate task for outside assistance. Consultants with special expertise can often provide solutions for specialized problems. For example, if inadequate burner controls are found to be the cause of excessive fuel consumption, an expert on burner control systems would be valuable. Perhaps this guideline could be stated as an admonition that having your staff re-invent the energy management wheel is almost never cost effective.

Energy Audits and Inspections

The first problem faced by a new energy management organization is compilation of the data necessary to perform analyses and make decisions. Lack of adequate data is undoubtedly the central factor when an energy management program fails. And it frequently serves as the rationale for inaction. The energy audit is the mechanism by which the data necessary for energy decision-making are compiled. It is usually accompanied by the energy inspection.

An energy audit is simply an accounting of the use of all forms of energy by all elements of the company operation. It should be written both in terms of energy units (BTU's) and dollars, and it should recognize the fact that the use of energy as a commodity can affect corporate profitability. The energy inspection is a detailed check of the physical facilities and equipment to identify areas where energy is not being used as efficiently as possible. The central purpose of the audit is to generate baseline and evaluation data, whereas that of the inspection is to develop recommendations for remedial action.

Like so many other aspects of energy management, the energy audit does not involve new methodology or technology. It is simply the application of common accounting sense to energy supply and consumption within a plant or other definable segment of a company's operation. It is new only in the sense that not until recently was energy regarded as something of sufficient value to warrant accounting.

The primary tool in the audit is the energy balance. The entire operation--both production and non-production units--should be conceptually divided into well-defined elements and an energy balance should be constructed around each element. These balances consist of energy flowcharts which identify where and how much energy of various forms flow into and out of a process or operating element. The flows should be established both in terms of conventional measures of the various energy forms (cubic feet of natural gas, gallons of fuel oil, tons of coal, kilowatt-hours of electricity, etc.) and in BTU's. The latter then represents a common comparative measure.

A simplified energy balance for a refinery is illustrated in Figure 1. This would represent an overall plant balance. Energy balances would also be drawn around the hydrogen plant, the ammonia plant, the steam system, the columns, and other processes. In many cases, the processes will not be adequately instrumented to obtain the necessary measures. One of the functions of the audit should be to determine where additional instrumentation is needed and whether or not potential savings justify the cost of their installation.

After the energy balances have been constructed, determine the theoretical amount of energy of each form required to carry out each process. This step is not as complex as it might seem. However, the time available to compute the energy balances and the capital available to purchase and install instrumentation are likely to be the factors which determine the degree to which operations can be disaggregated, i.e. the fineness with which the boundaries of the energy balances can be drawn. Some companies which have undertaken energy management programs have found that they have some plants where natural gas consumption or electricity demand is measured only at input to the plant. They have no measure of which processes consume the most energy or are the most inefficient. The first audit task in these cases is usually additional measurement.

One format for recording audit data is the audit balance sheet. In its simplest form it consists of a four-column log with entries for: (1) process description; (2) theoretical energy required to carry out the process; (3) actual energy consumed; and (4) energy difference between actual and theoretical requirements. Figure 2 is an example. The frequency with which this audit should be compiled depends on the manpower available and the frequency with which the energy consumption of a given process can be expected to vary.

Daily records of energy use by source (oil, gas, electricity, etc.) for overall operations are essential. For some process or production units, more frequent data will be necessary. One format for plant or facility records is a graph of energy demand for each source, production statistics, and degree days all plotted as a function of time. Degree day data are available from the weather bureau and can be calculated from records of ambient conditions usually made at power plants. Displaying the important elements of the audit data in graph form is an effective way to identify trends and spot unusual energy events.

Energy audits should be the responsibility of the energy control teams. The unit energy program manager should be required to submit energy balances at specified intervals (weekly, monthly) for all process or production units for which he is responsible, the boundaries of such units having been previously defined. Perhaps overall energy balances would be required more frequently, in some cases daily. Development of energy balances can be time consuming. But the audit is the key step in an energy management program and, therefore, deserves the investment. Data collection and storage systems can range in sophistication from manual collection and processing of data from strip charts and instruments to measurement systems which are on line with a central computer and automatically collect and analyze the data.

Tracking charts are a valuable tool in interpreting the information compiled by a continuous audit. They utilize the production or through-put data for a process step or production unit to determine the energy consumption per unit productivity, for example, kilowatt-hour electricity per pound of product or pounds of steam per pound of through-put. These data are plotted as a function of time. Both the theoretical process energy demand and the goal value can be displayed on the graph. Examples of a tracking chart are shown in Figure 3.

At the same time the first energy audit is being carried out, or before, a careful examination of energy costs should be undertaken in order to develop energy cost projections. The objective, of course, is to develop planning data on which to make decisions regarding the amount of effort which can be devoted to an energy management program or the future impact of energy on the corporate budget. And this requires estimates which apply to the specific company--estimates which reflect the realities of a given geographical region and a specific class of energy consumption. Fuel prices must be considered in planning, but developing projections in which one can have confidence is a difficult task. Of the several projections of fuel prices made in 1972, we know of none which has not already been proven to have forecast prices much less than actual. Indeed, prices of most energy forms (especially crude oil and refined petroleum products) which were actual in the first quarter of 1974 exceeded the prices which were projected for much later periods.

Economic models are necessary to forecast price trends. They require assumptions concerning demand, price elasticity, interfuel competition, exploration and finding rates, and numerous other factors. The work of Spencer and Decker* is among the most recent energy cost projections.

*R. S. Spencer, and G. L. Decker, "Fuel Price and Supply Trends--The Ups and Downs of the Energy Challenge," presented to the American Public Power Association, San Francisco, California, June 26-28, 1972.

R. S. Spencer, and G. L. Decker, "Energy Supplies and Cost Trends in the 1970's," presented to the Technical Association of the Pulp and Paper Industry, Chicago, Illinois, March 6, 1973.

But the actual prices paid for energy by a specific company can differ markedly from national averages or from the figures of any given model. Therefore, the energy manager must devote whatever effort he can to the development of fuel price projections which are tailored to the extent possible to his own company. He cannot, of course, simply extrapolate his company's past fuel and electricity price records. Industry is now operating in a new era of energy economics and the past affords no reliable guidelines. Apply common sense and realism to cost projections. Discuss cost trends with energy suppliers. It might even be desirable to develop formal interview instruments to solicit realistic responses from suppliers. And when needed, call upon resources outside the company to help prepare energy cost projections.

Closely related to energy cost projections are the economic analyses which should be carried out to determine the investment which can be justified to save a specified amount of energy. The discounted cash flow, net present value method is an often-used technique for determining how much capital can be invested to conserve energy for a specified number of years. It is based on the recognition that monies currently available can be invested to earn additional funds for the company, whereas monies received at some future date have no earning power until after they are received. Money on hand today is more valuable than money to be earned in the future. Thus a time value must be considered in the analysis of new capital investments. The net present value of an operation is defined as the net cash flow (accounting for cash flows into and out of the company due to the operation) after taxes and discounted to the date at which the operation commences. The results of this type of analysis can be displayed as a plot of the capital which can be invested to save a specified annual dollar amount of energy.

The energy audit is the fundamental mechanism by which information is compiled for an energy management program. It must be well planned and executed, and it must be a continuing effort. It should be the subject of periodic examination which covers four areas. First, a review of the data collection process to identify points at which the process can be improved or updated. Secondly, the energy program coordinator should observe the actual data collection process to see that the specified process is being followed. Third, the accuracy of the data should be periodically checked and compared with that required by the program. And the fourth function is a periodic examination of the costs associated with energy data collection to make sure that the value of the data exceeds the cost of its collection.

Energy inspections are designed to pinpoint energy inefficiencies. They consist of walking inspections of every segment of the company operations--from production units to storage sheds, from stockroom to boardroom. The purpose is to identify and record procedures, equipment, and processes which might be candidate targets for energy conservation. Like the audit, the energy inspection is conducted by the energy control team. But the team members must be trained and the inspection must be planned.

The inspector must be someone familiar with the operations. But more importantly, he must know what to look for to spot wasteful practices. He must be familiar with the energy conservation literature and how the ideas reported therein apply to his operations. For example, if those operations involve use of process steam, he should be aware that inadequately maintained steam traps can be the cause of much lost energy. He should know what parts of his operation are big energy users. He should have copies of the energy audit and the energy balances. This background should be applied to the design of an energy inspection checklist. Numerous lists of many ways to conserve energy in commercial and industrial operations have been published. These can be helpful in the preparation of the inspection checklist.

Inspections can be carried out with less frequency than energy audits. The first inspection might be made at the same time as the initial audit, but the audit data are usually very useful in designing the inspection. Both audits and inspections can be used to evaluate the implementation and progress of various energy conservation actions. Formal inspection reports should be prepared and submitted to the program coordinator. It should include recommendations for remedial action. Case histories of the successes and failures of energy conservation programs in other companies can help in designing the inspection checklist and in formulating ideas to improve energy efficiency.

Figure 1

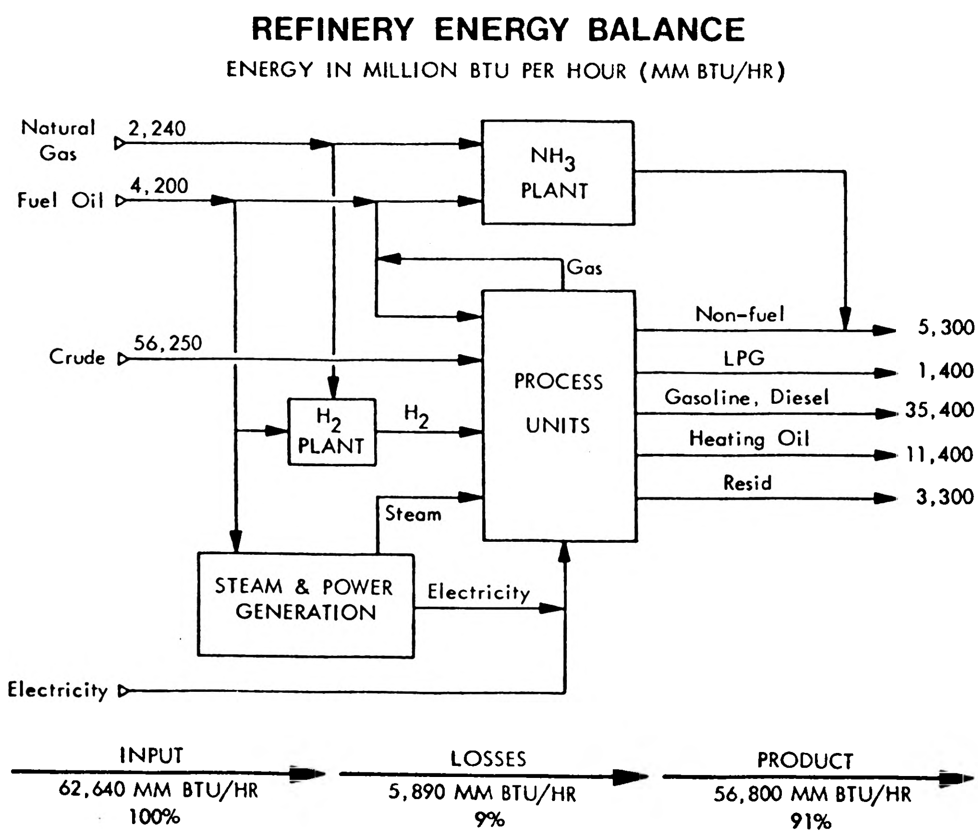


Figure 2

SAMPLE ENERGY AUDIT FORM

ENERGY AUDIT

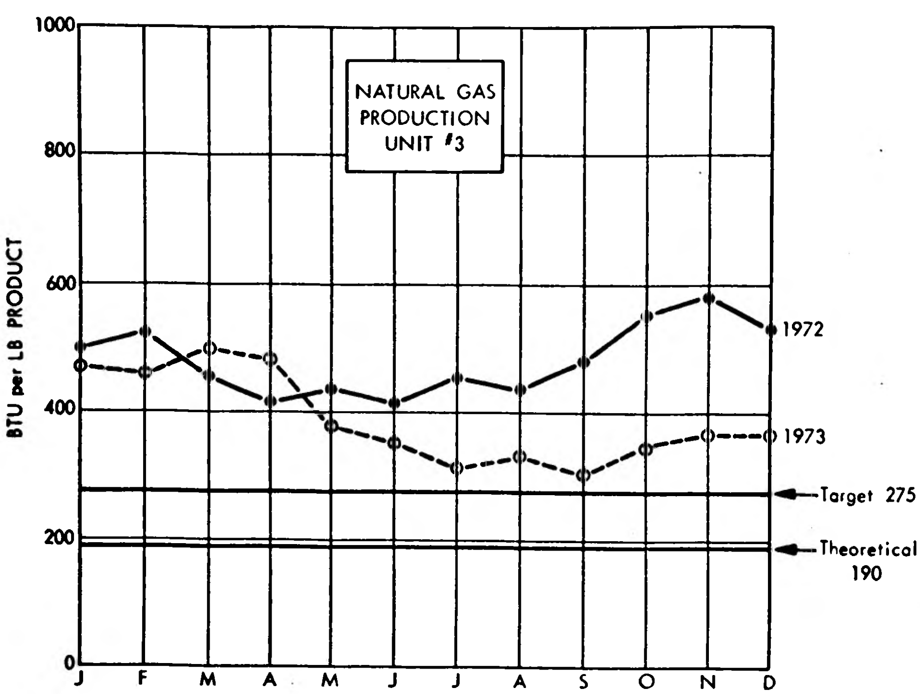
Plant: ______________________ Date: ______________________

Auditor: ______________________

PROCESS DESCRIPTION		THEORETICAL ENERGY		ACTUAL ENERGY		ENERGY DIFFERENCE	
Process	Fuel/Energy	Conventional Units	BTU	Conventional Units	BTU	Measured	Goal

MRI

Figure 3



TRACKING CHART