PROCEEDINGS OF ANNUAL SYMPOSIUM 'ENERGY RESEARCH AND DEVELOMPENT' (5TH) ON 13-14 MARCH 1974, SPONSORED BY THE AMERICAN DEFENSE PREPAREDNESS ASSOCIATION

EDGEWOOD ARSENAL ABERDEEN PROVING GROUND
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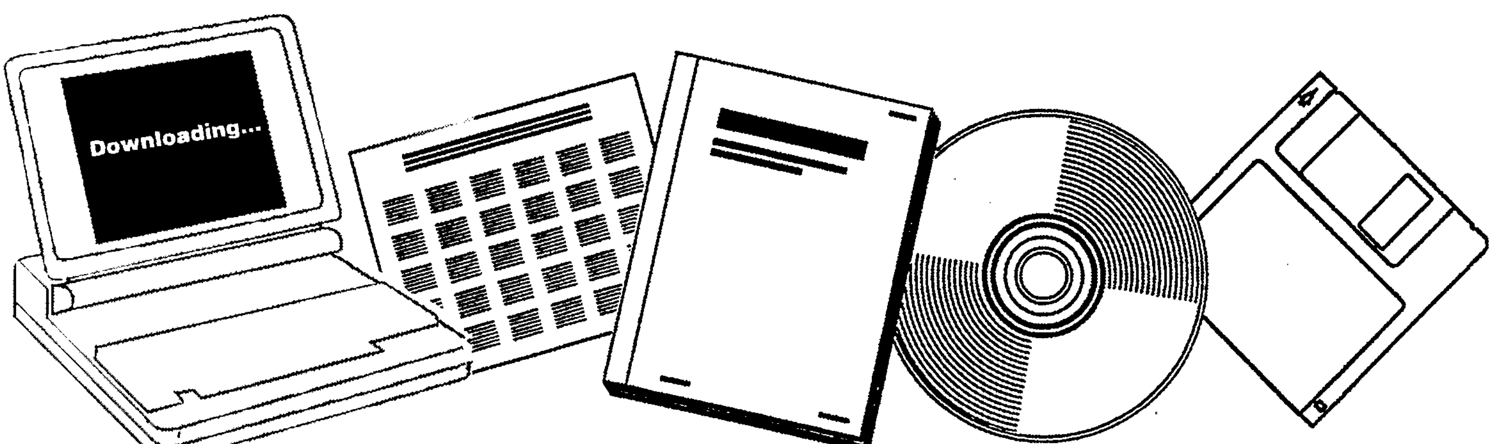

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PROCEEDINGS OF FIFTH ANNUAL SYMPOSIUM "ENERGY RESEARCH AND DEVELOPMENT" 13-14 MARCH 1974, SPONSORED BY THE AMERICAN DEFENSE PREPAREDNESS ASSOCIATION

Compiled by

Donald Falconer
Bernard Gerber
William Magee

Office of the Technical Director

January 1975

DEPARTMENT OF THE ARMY
Headquarters, Edgewood Arsenal
Aberdeen Proving Ground, Maryland 21010

PREFACE

The information in this report is a compilation of papers presented on the general topic of energy at a symposium sponsored by the Chemical-Biological (CB) Division of the American Defense Preparedness Association (ADPA) and the Chesapeake Chapter, also of that Association.

The symposium was privileged to present a large list of prominent leaders and scientists from government posts, from university faculties, and from industry. The meeting was convened in the Base Theatre, Bolling Air Force Base, Washington, DC, on 13 and 14 March 1974. The selection of Bolling as a conference location was made as a matter of convenience for the speakers and the subscribing ADPA members. That selection generally was marked with a measure of serendipity because the waiting lines for gasoline were at their longest during the last 2 weeks of February and a conference site dependent on extensive driving could have proved disastrous.

The report originates from Edgewood Arsenal by reason of the generous policies of COL Kenneth L. Stahl, Commander, and Dr. B. L. Harris, Technical Director. The relationship between Edgewood Arsenal and the American Defense Preparedness Association has always been exceptional and the objectives of the CB Division, ADPA, correspond closely with the mission assignments of the Arsenal. Furthermore, the Chesapeake Chapter has among its officers and members a large number of Edgewood Arsenal personnel, both military and civilian.

During 1974, COL Stahl and Dr. Harris have supported and are supporting the ADPA in three ways:

1. They have permitted the program committee for the symposium to function as necessary, freely and effectively, during the planning phases which began as early as October 1973.

2. They supported the conference at Bolling Air Force Base by their personal attendance and by authorizing that Edgewood Arsenal should provide a highly competent projectionist and a selection of audio-visual and amplification equipment.

3. They have authorized the appropriate organizations of Edgewood Arsenal to compile, edit, print, and publish this report, and to make the product available to the sponsors for distribution.

The use of trade names in this report does not constitute an official endorsement or approval of such commercial hardware or software. This report may not be cited for purposes of advertisement.

Acknowledgments

The sponsors of the Energy Symposium wish to acknowledge the invaluable assistance of:

1. The Vice-Commander of Bolling Air Force Base and his staff for the use of the Base Theatre and both the Commissioned and Noncommissioned Officers' Open Messes.

2. COL Kenneth Stahl and Dr. B. L. Harris, the Commander and Technical Director, respectively, of Edgewood Arsenal, for the support outlined in the Preface above, and for the highly competent assistance of Mr. Robert Dugent, Audio-Visual Equipment Specialist.

3. The Program Committee for its collective effort in selecting and formulating the program. General Conference Chairmen were:

COL (Retired) Norman I. Shapira
Hydronautics, Inc.
Chairman, CB Division, ADPA

Mr. Richard Zelina
AAI Corporation
President, Chesapeake Chapter, ADPA

Mr. Donald Falconer
Program Chairman, Session I
Edgewood Arsenal

Dr. William Magee
Chairman, Session II
Edgewood Arsenal

Mr. Bernard Gerber
Chairman, Session III
Edgewood Arsenal

Mr. Bernard Zeffert
Chairman, Session IV
Retired from Edgewood Arsenal

Dr. Solomon S. Love
Program Advisor
Edgewood Arsenal

Mr. John Garber
Logistics and Arrangements
Edgewood Arsenal

4. The Symposium speakers, identified elsewhere in this report, who provided the total substance of the meeting through their individual efforts and their most effective reviews of current programs in the energy fields.

On behalf of the sponsors, it is a privilege to acknowledge these individuals and to offer this report as a serious contribution to the energy problem which faces the United States and which will be reflected directly in the quality and substance of defense capabilities.

DONALD W. FALCONER
Office of the Technical Director
(Program Chairman)

EDITOR'S NOTE

To aid the publication of these proceedings, scripts were supplied by all speakers except four. These were:

1. The keynote address by the Honorable Rogers C. B. Morton, Secretary of the Interior.

2. Energy R&D Programs in the National Science Foundation by Dr. Alfred J. Eggers, Assistant Director.

3. Programs in the American Petroleum Institute by Mr. Bobby R. Hall, Assistant Director for Marketing.

4. Programs in the National Coal Association by Mr. Joseph P. Brennan, Vice-President.

All of the above talks were taped during the symposium by Mr. Robert Dugent who served so ably as audio-visual equipment technician. After it became apparent that scripts would not be available, the talks listed above were transcribed directly from the tapes through the gratuitous and generous efforts of Mrs. Lydia Falconer, lifelong helpmate of the Program Chairman.

It is the opinion of the editor that the substance of the talks and the intended emphasis of these four speakers have been conveyed with reasonable accuracy in this publication.

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Project Independence, which is really a project for a rapid escalation of basic supplies of conventional fuel, because the time frame of Project Independence is a period of time that only spans 6 years, between now and 1980.

We will have to have project "long term," or whatever you want to call it, starting now so that in the 1990's and in the first quarter of the 2000's, for the first 25 years, we've got an overlay that will give us transition from our fossil fuel dependence to more sophisticated forms of energy. And there is no substitute for this. Arab oil is not a substitute. If we got all of the Arab oil that we could expect, which is about two million barrels a day, or about 10% of their total production, we would still have instead of about a 15% shortfall, about a 7-1/2% shortfall. So Arab oil shipments to the United States won't put Simon out of a job all of a sudden. We still have this job to do.

And where you come into it, as a group of industries that are dedicated to the proposition of our national defense, is that for us to really have a national defense we must have a strong industrial economy. I don't think people really understand the relationship between our industrial economy and our national defense in the way that it really is. I think they see the military as something over here apart and, unfortunately, as a football that is kicked around by people that don't know what they're talking about. And then they label industry as another bad boy over here as sort of a bunch of greedy guys that are trying to make a lot of profit. And this just worries me to death. In the first place, the two are completely interdependent. We have a modern military that depends on a very sophisticated material and weapon inventory that must be competitive with other world forces down to the last bolt and nut; and we have to have highly specialized and trained individuals to be able to fight with those materials if the day should ever come. If those two things get out of step, we're in desperate shape. Now, they can get out of step if industry does not have a ready supply of energy to produce the kind of materials that the military has to have, and the military gets out of step if they don't have the energy to utilize these materials fully if they have to, and to train these people fully who have to be specialists to use the equipment.

Energy gets to be the key thing. The responsibility that I see that we have at the Department of Interior in the next couple of decades is to increase rather substantially the supply of conventional fuel and, hopefully, the Atomic Energy Commission will have the same attitude in terms of increasing the supply of energy produced by the nuclear process from uranium – with the hope of bringing on line as fast as possible these fuel-saving types of nuclear facilities, such as the breeder reactor and, hopefully beyond that, a fusion type of process.

Today nuclear power contributes about the same amount of energy as firewood – a fraction of a percent – and, if we don't come up to about 5%, 6%, 7%, or even 10% in the next decade, when we get these plants on the line, we haven't really done anything. It seems to me that we are rather slow, considering that it has been almost 30 years since the first nuclear device was actually used.

I take the thought very seriously that perhaps we have to change some of our environmental approaches and controls in order to increase the amount of fuel available. The first thing we have to do is look where the most likely places are to find an increased supply of oil, because we are oil-oriented right now, and it's going to take some lead time to convert oil-using facilities to coal-using facilities, for many reasons. The most likely place is the Outer Continental Shelf. The structures there, based on the geological knowns, look good and look promising.

But remember this, even with the sophisiticated geological techniques and seismic procedures, the ratio of dry holes to wet holes on the Outer Continental Shelf are 5 to 1; 5 dry holes to one producer. This means that 80% of the drilling rigs are drilling dry holes and we have operated under a policy of not allowing preliminary exploration through core drilling. We sell a lease to industry on the basis that "O.K., if there's oil there, you're all right – if oil is not there, we want our money anyway." We've been selling dry holes for a lot of money; that's why 66% of the revenues have gone to governments and 33% to the oil companies. I'm not for giving away any of the oil but I am for exploring the Outer Continental Shelf and finding out if there is oil there and then selling the oil at a good price, but not tying up an industry, 80% drilling for dust and 20% drilling for oil. We've been in the Outer Continental Shelf business for 20 years and we are producing less than a million and a half barrels a day from this tremendous resource. The on-land opportunities are now somewhat limited. One out of 60 drillings produces a field, and only one out of nine drillings on land produces any oil at all. We have depleted the fields with primary technology, having left in the ground, however, two barrels for every one we've taken out. That will have to be recovered through secondary and tertiary investment. And that's a pretty high-priced proposition and this is another argument for not letting the price roll back too far. But that is where we stand.

Now, as I said, over the long pull we've got to come up with a second program. First, the "A" program – Project Independence – will increase the supply of conventional fuel to get us back on the slab. Second, bring along the more sophisticated synthetic fuels from coal, oil from shale, a usable system for solar energy, a more efficient conversion of fuel into electricity such as through the fluid bed and through magnet hydrodynamics. And all that has to be brought together so that you have a technological transfer at a time when your conventional fuels are getting harder to get and you are reaching into the planet deeper and deeper and deeper; a more costly situation for them.

Now, there isn't any alternative to that, that I know of, unless we accept paralysis as the alternative. We are an energy-consuming society and we are not going to be substantially affected over any period of time by the amount of oil we can get from the Persian Gulf. Remember that the whole Persian Gulf production is just about even with the United States demand. If we get it all, we would be getting about 20 million barrels a day and we are using 18. This would leave all of Europe, Japan, and the developing countries completely out of business, and it would be the end of any sort of international trade as far as the United States is concerned. So we can't expect a large percent of that oil. Therefore, we have no alternative than to proceed in an orderly way to begin on the one hand to develop our supplies at a much higher rate, growing them at 6% or 7% a year for the next few years; and on the other hand, the demand side, reducing through conservation and efficiency the growth of demand from its present exponential rate down by a factor of 2% or 3%, hopefully even 4%, if possible. Now this is going to change our life style and this is going to do all kinds of things. I haven't the time to get into that but your own imaginations can supply it.

I shall be very happy to try to answer any questions that you have but I want to conclude with this thought: that this is not a catastrophic situation over which we should be depressed. The situation is that we are blessed. We are blessed with coal in the ground; it's coming out of our ears. We have 600 years of oil in the ground in oil shale at the usage rate of three million barrels a day. We probably have more oil undiscovered, based on geological knowledge, in the whole hemisphere; that is, the Arctic, the Alaskan area, and the two coasts, the gulfs, etc., than we have ever discovered up to this point in time. We have billions of barrels of oil in the Arctic. The challenge is to develop the resource, bring it into the market place, provide a return on capital, and to protect the environment against pollution, and all the rest, which we can do with clean technology. So don't be depressed about the energy situation. Be thankful that God endowed this continent with these tremendous resources and be glad that we, the American people, when put to the line, have the skill, the determination, and are willing to put our shoulders to the wheel to develop these resources so that we have abundant energy supply on which we can build an economy, remembering, too, that we shouldn't build it with the idea of wasting it. Energy will be at a price where wasting it will be less attractive.

Thank you.

KEYNOTE ADDRESS

by

The Honorable Rogers C. B. Morton
Secretary of the Interior

Thank you, Mr. Chairman. Ladies and Gentlemen of the American Defense Preparedness Association, I consider it a real privilege to be here because I think we have a lot in common; we have all been kicked around a bit by this energy situation and I'm going to get into that in some detail. My format here this morning is to discuss where we have been, where we are, and where we are going, thus setting a perimeter for this discussion. I will be glad to answer questions after we get through with these few general remarks.

I am reminded of a story and, since the General is familiar with my part of the world on the Eastern Shore, I'm sure he will understand and appreciate this story I have for you this morning. This is a true experience which resulted from a rather serious accident which occurred on the Eastern Shore. I was going to Seneca to hunt doves with a friend of mine. He was a lawyer involved in a case in court so I dropped into the courtroom to wait for him. There was this constituent of mine in the court, a farmer who was in a cast up to his hip on one leg, had a cast on his arm, had his head all bandaged, and looked in poor shape. His case came up – an obvious insurance case – and the Judge said to him, "George, how do you feel?"

George said, "Gosh, I feel pretty rough, Judge. I don't think I'm going to make it. I'm about dead!"

The Judge said, "I don't understand that because I've got your accident report here and I've got Lieutenant McIntyre's report here and he says he asked you how you felt and you said you felt fine, so I don't understand it!"

"Judge," George said, "you don't have the whole story!" So the Judge said, "Well, maybe I ought to have the whole story so tell me exactly what happened."

"Well, I was going home, minding my own business, on my wagon. I had been up helping my neighbor. I was out on that short stretch of highway that I have to get on to get home and, just as I was getting ready to turn into my gate, a great big semi-trailer jackknifed, collided with my wagon and knocked me off and into the ditch, and knocked my mule into the other ditch, and just tore us up. When I came to, I saw the blue light of the police car, and I saw Mac get out and walk over where the mule was. Mac shook his head and said, 'That mule is in bad shape,' after which he pulled out his .44 and shot her right through the head.

"Then he came walking across the road and looked down at me with that gun smoking in his hand and he said to me, 'How do you feel?' and I said, 'Hell, I feel fine!' "

I believe maybe that's the situation we are in after this energy situation has caught up with us.

I think several things concern me about our understanding of the energy problem. One is that we are apt to accept words like "crisis" and I'm not sure what crisis really means, but we have been headed for one at a pretty clip since, really, the end of the Korean War. For a point in time, when the demand curve and the supply curve crossed, which they did, I believe, in about the summer of 1971 (and again we saw a rather clear demonstration of that in the summer of 1973), we were beginning to draw down inventories and production was not increasing at the rate of demand.

Now the rate of demand since World War II has been fantastic. It had been doubling about every 15 years. We've been just on a real energy kick and we in the United States have been leading the parade by all odds. Now we've got to understand some other things that were going on within the energy demand situation.

Before World War II (and this just seems to be a pretty good place to cut off in time to look at the aspects of the change) fossil fuels of course were the dominant energy matrix. They still are and will be for some time to come. But the ratio of coal-to-oil was entirely different than it is today. About half of our energy was supplied by coal in the generation of electricity and in the operation of industrial boilers, etc. Even a large percent of our private dwellings were heated by coal. An iron fireman today is kind of an antique. It's a relic. But there was a tremendous number of them in operation and in use; they were in vogue in those days.

Now that we have gone on an oil kick, two things are noticeable: (1) There has been a tremendous increase in energy demand (just experienced) and (2) this increase, by 1975, will be about twice the energy consumption in 1960. We may anticipate, unless something happens, that even as more lights are dimmed, more thermostats are turned down, and more automobiles are driven fewer miles, that we would see in about 1990 another doubling of our energy demands.

All you have to do now is take your new little tricky pocket calculator (that everybody seems to have) and compound about 6% and you will see what happens in terms of the numbers of Btu that you have to supply in order to meet a demand curve that increases on a 6% compounded rate. That is what we have been looking at, while the supply increase has been proceeding at a more arithmetical rate and at a much lower pace. And this is natural. We were, in the 1960's, debating in the Congress what we were going to do with our surplus oil. What we decided was that coal was too dirty for us, that coal was too inconvenient, and that coal had all kinds of other connotations. It got to be kind of a political proposition because of the hazardous conditions in the mines and all the rest. I'm not arguing with that in any shape or form; that's not the mission here. But we dropped coal from about one-half to about 17%, less than 20% – from one-half to one-fifth – and the replacement of coal was oil primarily. Oil for everything. The fact is, I was first aware of the crisis when I went to visit my brother in Kentucky and found him burning Old Forester and drinking crude!

We got on this oil kick and, in the 1960's, the oil industry went overseas. Posters were read not on how pleasant the beaches were or how pretty the girls were, but with the view that there was the site of the best return on capital. During the 1960's, very little was added to our refinery capacity and very little profitable production was added to our basic oil production capacity. Of all the revenues that have been taken out of the Outer Continental Shelf, in terms of oil and gas, 66% of them have gone to governments – state and local and federal governments – and 33 1/3% have gone to the oil companies. So the return on investment for oil that has been produced and the gas that has been produced on that Outer Continental Shelf, which was the great hope after we had begun to deplete the onshore fields, did not represent a profitable investment at prices that existed. So they went other places.

Then we went through the problem of the import policy. Then all of a sudden the demand curve and the supply curve crossed and just as quick as that we were in a seller's market as opposed to a buyer's market for oil. In the meantime, we had become dependent on oil for everything. The petro-chemical industry provided us now with so much material – plastics and all the rest. Recall our fantastic consumption of gasoline with an annual growth of automobiles on the road of seven million a year. We paved the country.

There are only one or two little areas left that are not under concrete, and we are charging admission to see them! And we started running back and forth at 75 miles an hour – go to Yellowstone for a weekend – go out to California to see an old classmate – drive out on Saturday and Sunday and come back on Wednesday and Thursday – spend one day there – it's been done! O.K. So there's where we are.

These things happened and we have reached this point in time – a fantastic inventory of internal combustion engines with a fantastic demand for material made out of petroleum, with most of our old coal-burning machinery in the museums off the line. And there is a tremendous amount of gas being burned under boilers which is, in my opinion, disgraceful because this is a fuel that can be used by the consumer much more efficiently and with much more contribution to the quality of life and the economy than using it under industrial boilers.

So where are we going? We're not going to solve the problem by letting the Arabs let us have two million barrels of oil a day, which is the historical Arab import level. We are still going to have to carry out the

SESSION I

ENERGY PROGRAMS

Chairman: Mr. Donald Falconer
Edgewood Arsenal

ENERGY RESEARCH AND DEVELOPMENT PROGRAMS OF THE UNITED STATES DEPARTMENT OF THE INTERIOR*

by

Dr. Harry R. Johnson
Assistant Director, Office of Research and Development
US Department of the Interior
Washington, DC

March 13, 1974

Secretary Morton has, this morning, clearly delineated why Project Independence must and will go forward and the demands this action will make on you. The interface between government and industry in this undertaking is the critical element in the rate at which we will become independent of foreign energy supplies and once again be the masters over our own energy destiny. I am delighted to join with you today to explore this interface and, in so doing, outline Interior's plans for fossil fuel research.

Let's start this exploration from the beginning – the energy system. How does the energy system of this Nation work? Where does Interior's proposed research fit? What will the research accomplish?

To answer these questions, the energy system has been depicted in simplified form in figure 1. This will enable us to establish some basic parameters for our discussion. The top part of this figure traces the flow of any energy source from discovery through end use; the middle row the key stages in the energy cycle; and in the third row, the estimated potential energy available at each stage. What is immediately apparent from this chart is that our undiscovered fossil fuel energy resources are enormous when compared to what we actually use. Additionally, only about one-half of the total energy extracted actually contributes to end uses, which indicates that a significant target exists for energy conservation measures. However, potential resources must be discovered before they can be classified as a resource. Appraisal of the resource is then required to determine if the resource can be recovered with existing technology and at current prices. If these criteria are met, the resource is classified as a reserve. Extraction of a reserve results in the emergence of the energy in its solid, liquid, or gaseous form, and conversion translates the raw material into use by energy consumers.

End use is the key to the energy system, for its expansion dictates the amount of raw energy that must be withdrawn from the Nation's indigenous resource base or imported. End use also controls the type of conversion process that must be applied; for example, the quantity and quality of gaseous and liquid products made from coal. In turn, inadequate expansion of the reserve base will change end uses. For example, the changing patterns of automobile use is the direct result of inadequate supplies of gasoline and would have been avoided had we expanded our domestic reserve of crude oil.

Basically, then, the energy system is dynamic and continuously responding to numerous factors that influence the balance between demand and supply.

A more detailed representation of the energy system is shown in figure 2. This analysis developed from efforts by Associated Universities to provide a reference-energy system for the United States. In concept, it is identical to figure 1, but the steps to be performed have been further subdivided. Also, the energy resources that supply our needs have been identified.

*Based on the statement of Dr. S. William Gouse, Jr., Director, Office of Research and Development, Department of the Interior, before the House Subcommittee on Appropriations on Energy Research on March 4, 1974.

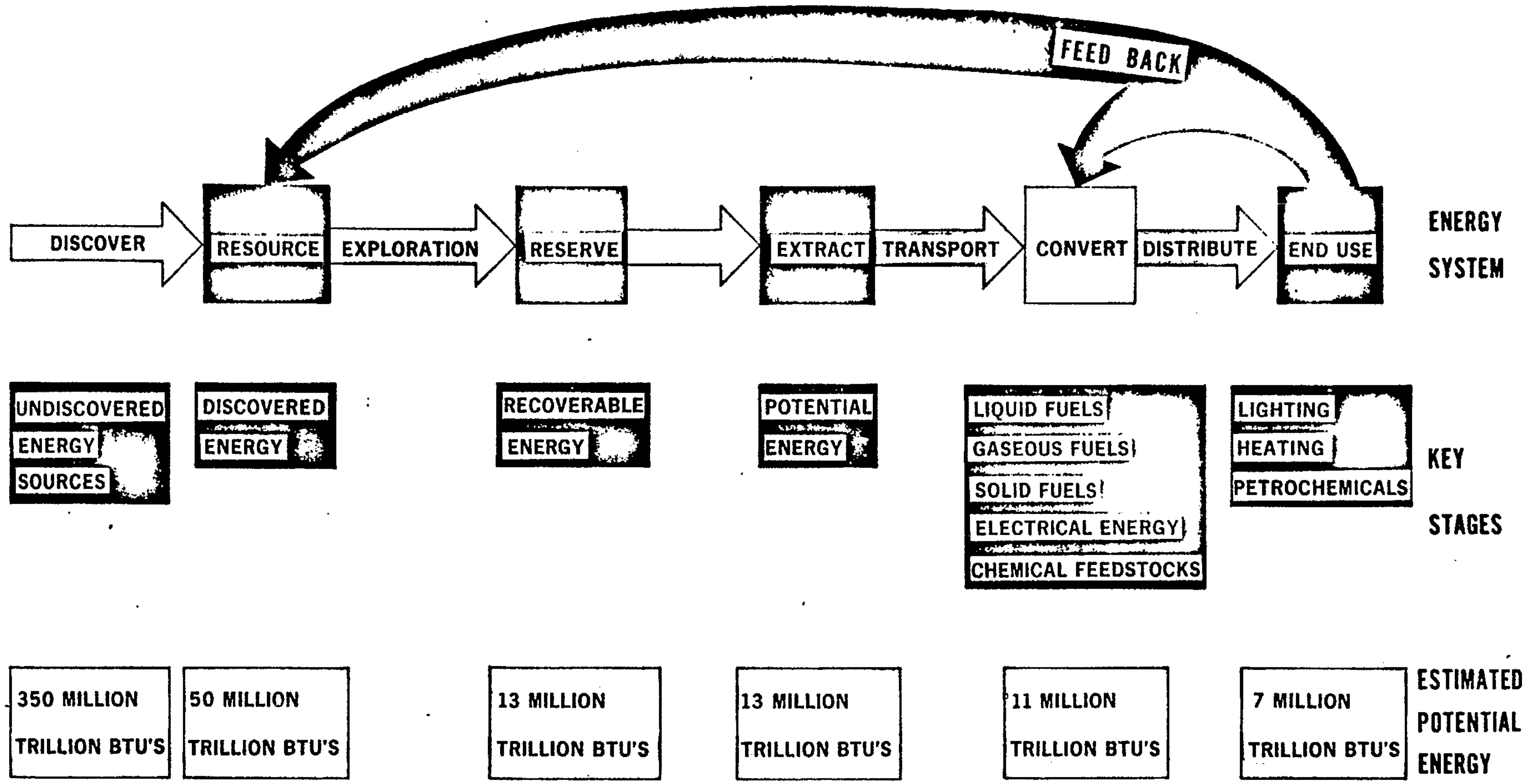

Figure 1. Simplified Energy System, Key Parameters, and Estimated Potential Energy

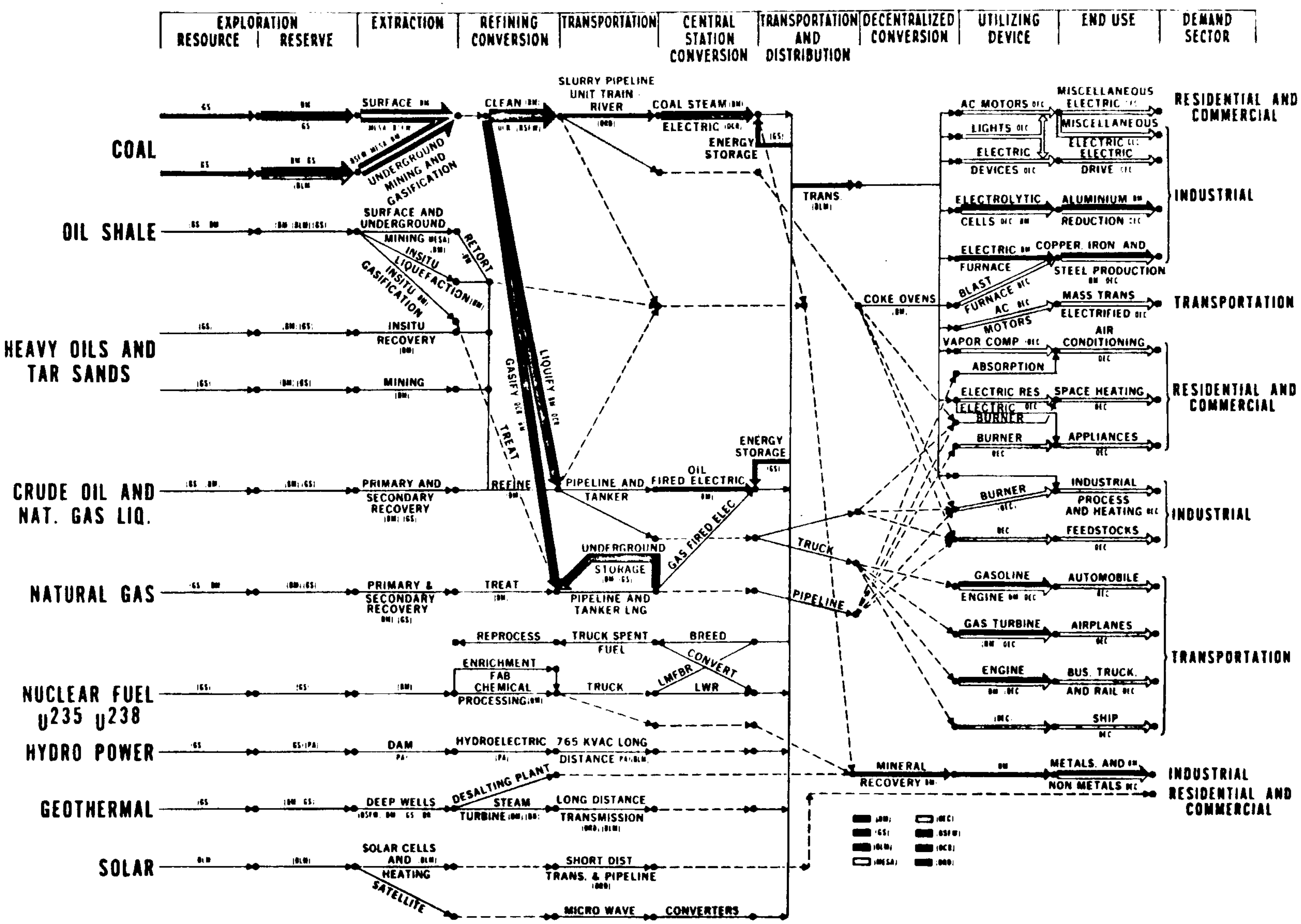

Figure 2. Major Energy Research Activities
United States Department of the Interior

Proceeding from the left hand side of this figure, one can take any energy commodity and trace it to its ultimate end use. It indicates how the flow of energy through the economy is controlled, how substitutions between energy forms take place, and how various energy forms contribute to the same end use.

For example, coal has been emphasized in this figure to show its flow from development by surface or underground means to end use. Note that under "refining and conversion" that the coal can be cleaned for use in direct combustion, or converted to liquid or gaseous products that enter the flow streams of other energy sources.

Such a chart, although complex when first viewed, serves as a useful analytical tool for guiding the Department's energy research program. For example, the Bureaus and Offices within Interior performing research in each area are identified on the appropriate links. The coal research program, which is the largest single effort, has been color coded to highlight various agency interests. Such a chart not only points out where the effort is concentrated, but it also reveals new opportunities for research: for example, the recovery of minerals such as alumina from coal wastes after the coal has been burned but before the waste material has been transported to a disposal area.

While useful from an overall point of view figure 2 does not reveal the level of effort devoted to a particular activity. This information is shown in a general way in figure 3. The intent in figure 3 is to visually relate the proposed distribution of expenditures by: (1) commodity, (2) agency within Interior, and (3) activity.

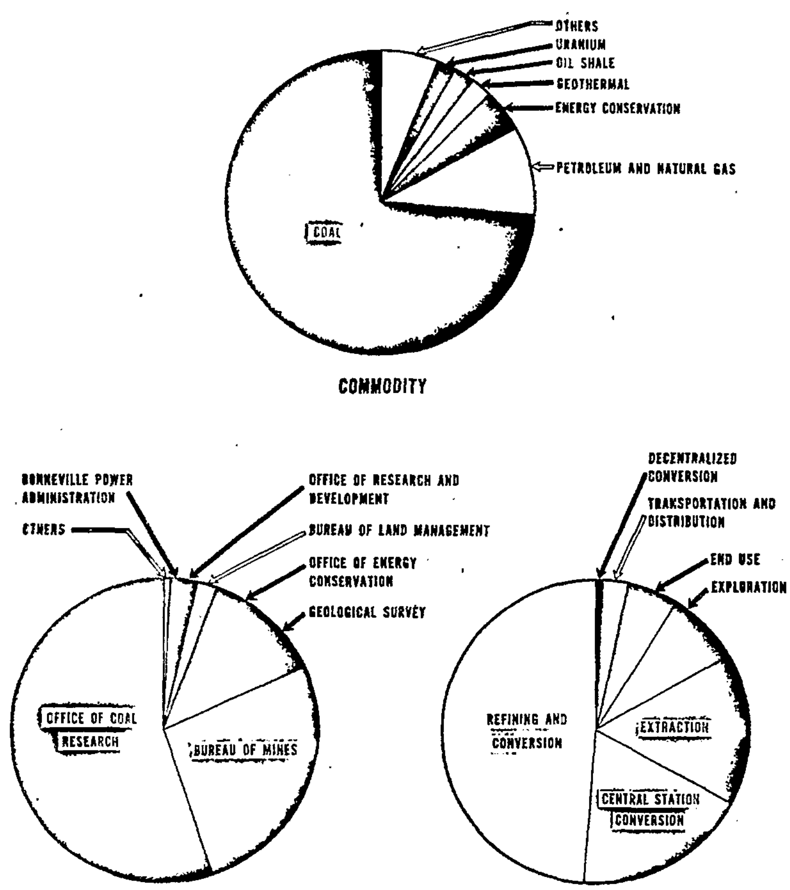

Figure 3. Energy Research and Development Budget ($512.5 Million)
and Related Programs ($36.5 Million)
(Total $549.0 Million)
Department of Interior

For direct energy research, we are proposing a level of $512.5 million and for energy-related programs, $36.5 million – a grand total of $549 million. The majority of the effort (about three-fourths) would be directed toward coal; 10% to petroleum and natural gas; 5% to energy conservation, and the remainder, 10%, to other energy commodities.

The Office of Coal Research (OCR) would manage over one-half of the funds, the Bureau of Mines about 25%, and the Geological Survey about 10%. As indicated in the third set of pie charts, about one-half of these efforts would be directed at research associated with conversion of coal to other energy forms, 20% to central station conversion, 15% to extraction of fuels, and 10% to exploration.

This chart is a useful overview, but lacks the detail needed to show the level of effort devoted to a particular activity. This detail is given in figure 4.

The Interior agencies are listed on the left hand side of figure 4. The number under the agency is the total proposed funds for energy research for that agency. These funds would be directed toward the various problems that have been discussed in the strategy section of our analysis. The projects proposed to overcome these problems and the level of funding requested are also given in this figure. Thus, OCR, for which we have a total request of $283.4 million, would spend $194.6 million on problems related to coal conversion. Of this total, $37.8 million would be directed to high-Btu (or pipeline quality) gas, $49.0 million to low-Btu gas, and $79.6 million to coal liquefaction.

Figure 4 can be considered to represent our best analysis of what is needed now. However, I must hasten to add that it is only one dimension of the total energy story. Our attack must be expanded and we have some ideas about how this may be accomplished.

Let's look at another dimension. Figure 5 shows the energy activities in the left hand column. These are the same activities that appeared across the top of figure 4. However, the "agency" headings have been replaced with "constraints." which are laws of nature or of society imposed on a particular commodity. In effect, these constraints act to retard the flow of minerals into our economic system. Obviously, some constraints are more important than others. For example, we cannot create fossil resources; nature has therefore established an absolute limit on the amount of fossil fuel we may ultimately find and utilize. The blocks in figure 5 show the kinds of problems which are of concern for coal development. This is not all-inclusive at this time, but we plan to systematically fill in all the major problem areas. This will be done not only for coal, but for each energy commodity of concern to our Department.

Taken together, figures 4 and 5 form the basis for our approach to research management. Visualize, for example, that we have taken figure 4 (the agency/activity matrix) and placed it at right angles to figure 5 (the agency/constraint matrix). This creates a figure that has agency, activity, and constraints as its coordinates. Such a figure can only be represented in three-dimension which we have drawn. This figure, number 6, has 640 separate blocks, which represent interfaces between an agency, an activity, and a constraint.

Two blocks have been removed from the matrix and have been enlarged to show how such a matrix may be used in planning and coordinating a major research effort. For example, these two blocks show the interface between the Bureau of Mines and OCR.

The Bureau is engaged in a much wider variety of activities than is OCR in their individual programs related to energy, mining, metallurgy, and mineral supply. This diversity extends to the subdivisions within these major activities. For example, within energy, the Bureau is conducting research on petroleum and shale oil recovery as well as coal conversion. Traditionally, these two agencies have conducted complementary coal programs – the difference being usually a matter of scale. This interface between the role of the Bureau and that of OCR has, in the past, been confusing and sometimes counterproductive toward the attainment of overall Departmental goals.

DEPT AGENCY / ENERGY ACTIVITY	EXPLORATION RESOURCE TO RESERVE	EXTRACTION	REFINING AND CONVERSION	TRANSPORTATION	CENTRAL STATION CONVERSION	TRANSPORTATION AND DISTRIBUTION	DECENTRALIZED CONVERSION	END USE
BUREAU OF LAND MANAGEMENT 10.8	OUTER CONTINENTAL SHELF - LEASING IMPACT STUDIES 10.8							
OFFICE OF ENERGY CONSERVATION 22.9								ENERGY CONSERVATION 22.9
GEOLOGICAL SURVEY 42.0	COAL 2.9 OIL AND GAS 15.5 GEOTHERMAL 9.7 URANIUM 4.1 32.2	COAL WATER SUPPLY AND QUALITY 2.6 OIL SHALE RESOURCES HYDROLOGY 2.2 4.8			COAL- ENVIRONMENTAL GEOCHEMISTRY OF COMBUSTION WASTES 0.5	UNDERGROUND HEAT STORAGE 0.1	URANIUM- ENVIRONMENTAL 3.33	URANIUM ENVIRONMENTAL 1.07
BONNEVILLE POWER ADMINSTRATION 5.5						HI-VOLTAGE TRANSMISSION 5.5		
BUREAU OF SPORT FISHERIES AND WILDLIFE 1.0		COAL- ENVIRONMENTAL 0.7 OIL SHALE- ENVIRONMENTAL 0.3 1.0						
OFFICE OF RESEARCH AND DEVELOPMENT 8.5						ELECTRIC POWER TRANSMISSION 8.5		
BUREAU OF MINES 137.1		INSTU- OIL AND GAS 18.9 OIL SHALE 2.0 MINING- COAL 46.5 OIL SHALE 5.6 73.0	COAL HI BTU GAS 22.2 LIQUEFACTION 27.4 ADV. HYDRO. CARBS 3.2 ORGANIC WASTE TO OIL 1.0 OIL SHALE CLEAN FUELS 1.0 GEOTHERMAL MINERAL ENERGY AND IMPROVED MATERIALS 0.3 URANIUM ORE PROCESSING 1.1 56.2		COAL- LO-BTU GAS 1.0 - ADVANCED POWER SYSTEMS 2.3 - STACK EMISSION CONTROL 2.0 5.3			OIL AND GAS - UTILIZATION 2.1 ENERGY USE PATTERNS 0.5 2.6
OFFICE OF COAL RESEARCH 283.4			HI - BTU GAS 37.8 LO BTU GAS 49.0 LIQUEFACTION 79.6 ADVANCED RESEARCH SUPPORT 19.14 SYSTEM STUDIES 2.5 ADMINSTRATIVE SUPPORT 6.56 194.6		ADVANCED POWER SYSTEMS 12.7 DIRECT BOILER COMBUSTION 34.0 PIONEER PLANTS 42.1 88.8			
BUREAU OF RECLAMATION 1.3		GEOTHERMAL 1.3						
TOTAL FUNDS 512.5	43.0	80.7	250.8		94.6	14.1	3.33	26.57

Figure 4. Agency Programs, Energy Activities, and Funding
(Millions of Dollars)

CONSTRAINTS / ENERGY ACTIVITIES	SCIENTIFIC KNOWLEDGE	APPLIED TECHNOLOGY	GEOGRAPHICAL	LEGAL AND LEGISLATIVE	POLITICAL AND SOCIAL (H&S)	ECONOMICS CAPITAL, TAXES	ENVIRONMENT	MANPOWER AND MATERIALS
EXPLORATION RESOURCES TO RESERVES	DELINEATE THE EXTENT AND LOCATION OF THE NATION'S COAL RESOURCES							
EXTRACTION		DEVELOP NEW MINING TECHNOLOGY TO SIGNIFICANTLY REDUCE MANPOWER AND INCREASE PRODUCTIVITY						
REFINING AND CONVERSION		DEMONSTRATE PRESENT KNOWN GASIFICATION AND LIQUEFACTION TECHNIQUES						
TRANSPORTATION			DEVELOP TRANSPORTATION NETWORKS TO DELIVER ENERGY, DERIVED FROM COAL, TO MARKETS					DEVELOP PLANS TO REDUCE SHORTAGES OF TRAINED PERSONNEL AND MATERIALS
CENTRAL STATION CONVERSION							IS IT FEASIBLE TO SITE PLANTS UNDERGROUND TO REDUCE POLLUTION AND IMPROVE LAND USE	
TRANSPORTATION AND DISTRIBUTION								
DECENTRALIZED CONVERSION								
END USE					HOW WILL THE CHANGING SUPPLY OF ENERGY EFFECT OUR NATION			

Figure 5. Energy Activities and Program Constraints Interaction of Matrix-Coal

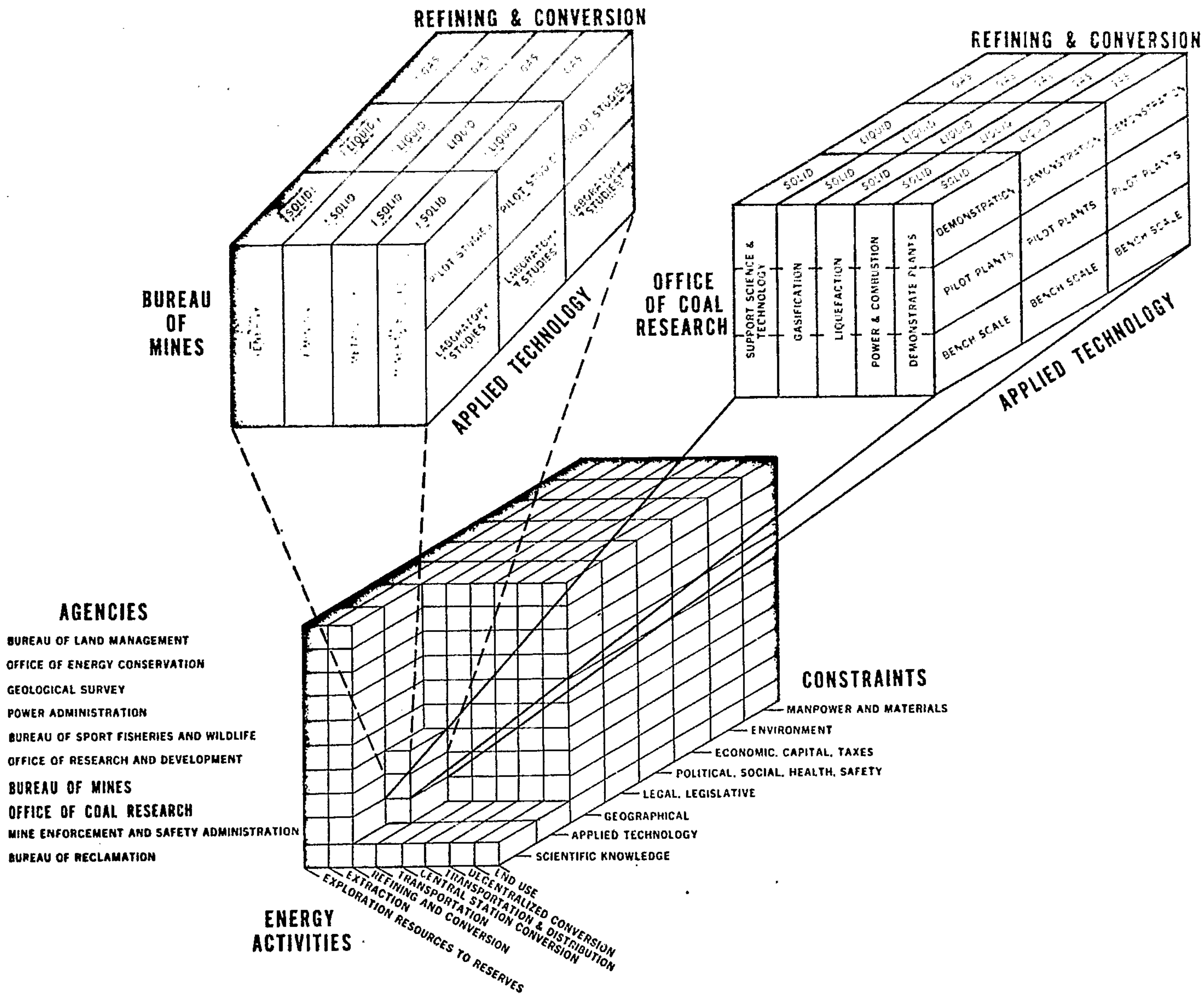

Figure 6. Exploded Three Dimensional Matrix for the Department of the Interior Research Program

We have taken the necessary actions to clarify this interface more precisely. For example, the Bureau of Mines has been given the technical lead in coal mine extraction research. This does not mean that OCR will not undertake any work in this area; but its coal mining program will be planned in accordance with the technical leadership assigned to the Bureau.

Also, OCR will be the Department's primary agency to sponsor pilot scale operations regardless of who developed the technology. For example, the Bureau has developed a stirred fix-bed reactor to produce low-Btu gas from coal. This unit is now judged ready for scaleup and funds are being requested in the OCR budget to advance this technology to pilot scale operation, probably in cooperation with the Tennessee Valley Authority. At the same time, funds are also being requested which will allow the Bureau to continue to research this technology and to provide valuable support to the larger operation.

Our examination of the interfaces represented in this model is continuing. We hope by next year to have filled in these boxes and to have extended our analysis to the interface between Interior and other Federal agencies.

This larger interface is very important for only by working together towards a common goal can we, as a nation, hope to achieve control over our energy destiny. What can be accomplished?

I believe that we can reduce both energy demand and oil imports to a level significantly below the level that would be attained in the absence of an accelerated energy research program.

The basis for this conclusion is the comprehensive report "The Nation's Energy Future." We have shown in figure 7 the results of that effort for alternative possible "futures."

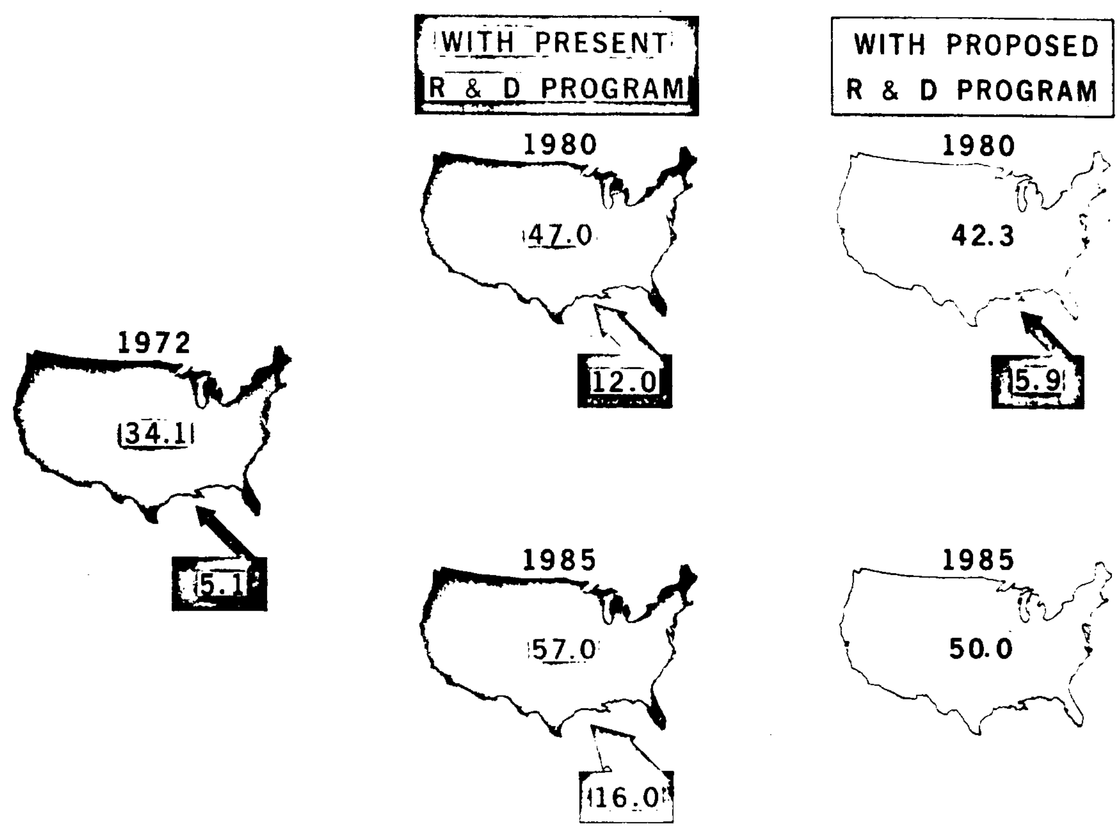

Figure 7. United States Production Requirements and Imports
Million Barrels Oil/Day Equivalent

On the left side of the illustration, you see the United States consumed the equivalent of 34.1 million barrels of oil per day in 1972. Of this amount, 5.1 million barrels per day were imported. With the present research and development program, both demand and imports are expected to rise dramatically. By 1985, demand will have increased to 57.0 million barrels daily and imports to 16 million.

With the accelerated but orderly program proposed in the "Energy Future" report, energy conservation is expected to reduce demand significantly and, by 1985, imports could be eliminated. The achievement of these results will indeed require a national effort; the Department's proposed program will provide an important contribution to this effort. The Project Independence team of the Federal Energy Office is presently investigating ways to accelerate this schedule.

This extended preamble has now led us back to the key question of the interface between the government and private industry. More simply put: How do you, as representatives of private industry, fit into Interior's energy research and development program? The answer: You *are* the program... for you will be called upon to join with us to conduct and then implement the results of this research. More specifically, nearly four-fifths of the money requested in the Fiscal Year 1975 will be contracted to private firms. How well you respond will therefore largely dictate the rate at which we will approach self-sufficiency.

Our goal must be to move forward together in a consistent and uniform manner under prescribed time limits. To do this, you must know early what the game plan is – and in sufficient detail to enable you to make advance plans.

We have detailed our program in a report to be published by the Government Printing Office in April. Entitled "Energy Research Program of the US Department of the Interior," the report is divided into two major sections, "strategy" and "tactics."

In the strategy section, we have outlined why specific actions have been emphasized. For example, the analyses included under coal extraction indicates that we cannot rely on surface reserves alone to support increased coal production through the balance of this century. Thus, the extraction research strategy is based on the premise that underground mining technology in both the East and the West must be accelerated. Also, the production of liquid fuels from coal, stimulation of conventional oil and gas reservoirs, and energy conservation are to be emphasized. Research on oil shale has been tailored to support the Department's Prototype Leasing Program.

Under tactics, specific research projects have been developed from our strategic analysis. Using coal extraction as an example once again, the tactics section includes projects related to both hardware development and supporting environmental concerns. The objective of each project is defined and funding is given not only for FY 1975, but funding implications are also estimated by year from FY 1976 to FY 1979 (figure 8). This provides an indication of future research emphasis. Also, the major milestones to be attained for each project over the 5-year period are presented. Thus, you have displayed in one place what is to be accomplished, how much it will likely cost, and the major technical achievements required to attain the objective.

Laying out our program in such detail has helped us crystallize what we, as a Department should do, and at the same time, provides a yardstick against which progress can be measured. We hope it also stimulates your interest and participation in our program.

Thank you.

Program: Coal Research
A. Subprogram: Extraction
1. Element: **Mining Technology**

BUREAU OF MINES
Energy Research and Development
Projected Five-Year Funding in $ Million

	FY 75	FY 76	FY 77	FY 78	FY 79	Total FY 75-79
a. Underground Mining						
(1) High Speed Mine Development Systems	4.0	6.0	6.0	6.0	5.5	27.5
(2) Automated Longwall	8.0	6.0	6.0	11.0	15.0	46.0
(3) Automated Remote Controlled Continous Miner	2.0	2.0	4.0	5.0	3.0	16.0
(4) Continuous Face to Preparation Plant Coal Haulage System	5.0	8.0	8.0	9.0	8.0	38.0
(5) Automated Continuous Roof Support	3.0	4.0	5.0	5.0	5.0	22.0
(6) Mining Systems for Western Coal	1.0	3.0	4.0	5.0	5.0	18.0
(7) Environmental Protection of Surface Areas Near Underground Mining Operations	5.0	5.0	5.0	5.0	5.0	25.0
(8) Recovery of Methane from Virgin Coal and Gob Areas	2.0	3.0	2.0	2.0	1.5	10.5
(9) Advanced Mining Systems	3.0	6.0	7.0	9.0	9.0	34.0
(10) Underground Gasification	2.0	2.0	3.0	3.0	3.0	13.0
b. Surface Mining						
(1) Improved Surface Mining (Extraction and Reclamation) Systems	4.3	4.0	4.5	5.0	5.0	22.8
(2) Surface Mining Equipment Development	4.0	7.5	7.0	8.0	8.0	34.5
(3) Geological and Geophysical Studies	1.7	2.5	2.8	3.4	3.8	14.2
(4) Baseline Ecological Data	.6	1.0	1.8	2.1	2.0	7.5
(5) Mineral Intelligence	.9	.9	.9	1.1	1.2	5.0
TOTAL	46.5	60.9	67.0	79.6	80.0	334.0

Figure 8. Funding Estimate Example from Report "Energy Research Program of the United States Department of the Interior"

AEC

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

Remarks Prepared for Delivery by

Dr. Stephen O. Dean
Assistant Director for Confinement Systems
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at the

Fifth Annual Symposium on
Environmental Research

of the

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ENERGY R&D PROGRAMS OF THE U.S. ATOMIC ENERGY COMMISSION

In recent months the nation has become acutely aware that shortages of energy–especially oil–threaten its social, economic, and environmental priorities. The ramifications of this shortage are very wide–ranging from relationships among nations to every day relationships among individuals.

Answers to the energy shortage must, correspondingly, be broadly sought. Actions must be initiated which will impact the shortage problem in the immediate future as well as in the near-term and long-range futures. The immediate problem will be alleviated by actions aimed at increasing fuel supplies and cutting consumption by conservation and sacrifice. The near-term problems, during the next decade or so, will be solved by introducing recently developed advanced technologies, such as nuclear fission reactors and coal gasification, at a more rapid rate. But these methods will be inadequate in the long run unless we resolve today to set about the serious business of solving our energy problems for the long-range future–1990's and beyond. This means vigorous research and development on programs such as techniques to improve efficiency and reduce waste; breeder reactors; development of radioactive waste disposal technologies which are environmentally acceptable; the development of solar and geothermal power technologies; and the demonstration of nuclear fusion as a practical source of energy for power generation and other purposes.

The status and needs for research and development on advanced energy technologies were intensively reviewed during the last half of 1973, at the request of the President. This led to a report (WASH-1281), entitled, "The Nation's Energy Future," submitted to the President by Dr. Dixy Lee Ray, the Chairman of the U.S. Atomic Energy Commission. That report reviews the existing Federal and private activities in research and development and recommends an integrated energy research and development program for the nation.

A five-year, $10 billion Federal energy research and development program was proposed to supplement an estimated $12.5 billion expected from the private sector during the same period. An additional $1 billion was recommended for supporting programs. The aim of the proposed national program is to regain and maintain energy self-sufficiency. It is estimated that 1985 is the earliest date by which self-sufficiency can reasonably be expected with this program.

By 1980 the recommended program is expected to reduce oil imports to half (6 million barrels/day) of those currently projected as needed. Other extraordinary measures would be required to restrict consumption, increase domestic production, or both, to displace the other half if self-sufficiency is to be achieved by 1980.

The study concludes: (1) that present energy problems stem, in large part, from the lack of a coordinated national energy R&D program over the last twenty years, and that only nuclear power has received sustained support at adequate levels; (2) that the requirement to regain and maintain energy self-sufficiency stems from conditions more fundamental than the current crisis, and that world-wide energy shortages impend as energy-intensive industrial growth spreads and accelerates; and (3) that the United States has the resources and technology for self-sufficiency, and that a properly directed, sustained national commitment can attain that goal.

Five tasks are identified to regain and sustain self-sufficiency. Simultaneous effort is urgently required on all five. Their contributions to self-sufficiency is expected to materialize in the following order:

Task 1. Conserve energy by reducing consumption and conserve energy resources by increasing the technical efficiency of conversion processes.

Task 2. Increase domestic production of oil and natural gas as rapidly as possible.

Task 3. Increase the use of coal, first to supplement and later to replace oil and natural gas.

Task 4. Expand the production of nuclear energy as rapidly as possible, first to supplement and later to replace fossil energy.

Task 5. Promote, to the maximum extent feasible, the use of renewable energy sources (hydro, geothermal, solar) and pursue the promise of fusion and central station solar power.

The recommended Federal expenditures and those expected from the private sector are shown in Table I. These recommendations were considered in the context of preparing the Federal budget for FY 1975. On January 23, 1974 the President issued his energy message and transmitted his FY 1975 requests to the Congress. These requests are shown in the last column of Table I and, as is readily apparent, his requests largely correspond to the recommendations contained in Dr. Ray's report.

The President has requested $1.8 billion for direct energy R&D in FY 1975. Of this total, 52% (or $933 million) is part of the Atomic Energy Commission's programs. A detailed breakdown of total Federal expenditures, showing the fraction supported by the AEC is shown in Table II. The AEC supports effectively 100% of the total Federal programs in nuclear fission and nuclear fusion which, taken together, constitute 49% of the total $1.8 billion. In other areas the AEC's programs constitute a relatively small fraction of the total Federal effort.

Today, nuclear power from fission reactors is a proven technology, economically competitive with other methods of generating electricity. During the past few years, over 60% of the commitments for new central station power plants have been for nuclear plants. This is not to say that nuclear power plants operate 100% of the time or are completely trouble free. The technology of nuclear plants, although proven for commerical application, is a rapidly developing one, and improvements, both large and small, are continually being made. In the United States about 5 1/2% of our total electricity comes from nuclear power. In Europe, nuclear power is having an even greater impact. In Germany, for example, nuclear power will supply 14% of the total by next year; in the U.K., 8% of the total capacity is presently nuclear. In the U.S. these nuclear plants are primarily light water reactors (LWR) and the costs of continued development of such plants are largely born by industry. In the U.S., enriched uranium for such plants is produced by the AEC and sold to the customers. The AEC anticipates revenues of about $670 million in FY 1975, primarily from the sale of enriched uranium.

The 5 1/2% fraction of the total U.S. electrical capacity, which is provided by nuclear plants comes from 42 operating reactors generating 25 million kilowatts. An additional 54 nuclear plants (to generate an additional 52 million kilowatts)are currently under construction. To produce this 25 million kilowatts from additional fossil fuel plants would require about 700,000 barrels per day of oil or 65 million tons per year of coal. Without these plants the current shortage would be about 25% more severe than it is. By 1980, under current procedures, nuclear power is expected to produce over 20% of the nation's electrical output—the equivalent of 2.5 million barrels per day of oil or 224 million tons per year of coal. The AEC is taking the initiative to revise current procedures in an attempt to reduce the total time for getting a power plant on line from the present eight to ten years to five to six years. Such a speedup could permit nuclear power to replace by 1980 the equivalent of as much as 3.6 million barrels per day of oil or 323 million tons per year of coal. This is more than half of all the coal produced last year.

The development of near-term commercial reactors requires a minimum Federal financial investment. The Federal challenge is to streamline licensing and regulatory procedures, while protecting the public safety and the environment, and to stimulate the private sector to develop a commercial uranium enrichment industry. Federal energy research and development programs, on the other hand, are aimed primarily at those next generation improvements which are sufficiently expensive and/or long-range that private enterprise cannot be expected to accept the full financial risks.

The Commission's largest energy R&D area is that related to nuclear fission reactors. These programs, and the associated AEC expenditures, are shown in Table III. The highest priority has been given to the development of the Liquid Metal Fast Breeder Reactor (LMFBR).

The need for the LMFBR can be understood as follows. Fissile material found in nature is confined to a single isotope of uranium (U-235). This isotope constitutes only 7/10 of 1 percent of natural uranium. The amount of U-235 now known to be available at reasonable cost ($8-30/lb U_3O_8) is less than the requirements projected for the rest of this century; consequently the cost of such fuel will rise dramatically. This situation is alleviated somewhat by the introduction of improved converter reactors, such as the High Temperature Gas Cooled Reactor (HTGR) which can convert a larger fraction of the abundant isotope U-238 to fissionable plutonium than do light water reactors, or can convert thorium to fissionable U-233. Increased enrichment capacity will be needed to supply the amounts of U-235 required.

The ultimate solution, however, lies in the development of breeder reactors which convert U-238 to plutonium, or thorium to U-233, at rates in excess of the rate at which they consume fissionable fuel. The new fuel which is "bred" in this way is then available to fuel new reactors. The resulting production should result in abundant fuel resources since the large reserves of natural and depleted uranium and thorium then become usable as fuels.

The Liquid Metal Fast Breeder Reactor is the primary U.S. effort aimed at demonstrating the commercial viability of the breeder reactor. Other concepts, notably the Gas Cooled Fast Breeder (GCFBR), the Light Water Breeder Reactor (LWBR), and the Molten Salt Breeder Reactor (MSBR) are continuing as options and as complements.

The AEC signed a contract in July 1973 for the construction of a 380 MWe LMFBR demonstration plant in Tennessee. This project, which is a cooperative effort with the Commonwealth Edison Company of Chicago and the Tennessee Valley Authority, is scheduled for completion in the early 1980's. Utility industry support for this project includes financial contributions in excess of $240M from about 350 investor and publicly-owned electric utilities. LMFBR plants are projected to have a major impact on the commercial market in the 1990's and beyond.

From the beginning of the nuclear age back in the 1940's, safety has been one of the principal concerns of nuclear scientists and engineers. At every step of the way, elaborate precautions have been taken to ensure the safety of nuclear systems. Hazards analysis and the engineering of safety features have been developed to a sophisticated state. The resulting safety record of the nuclear industry is truly remarkable. Nevertheless, we continue our research into nuclear safety so that no stone may be left unturned. Public safety must be ensured in a civilian nuclear power economy. We recognize that as the number of operating nuclear power plants increases there will be a corresponding large increase in the amount of radioactive waste products which must be processed and stored. Methods exist today to handle safely the present volumes of waste involved and we are confident that methods will be available as needed in the future.

Development is continuing on improved methods for solidification and for long-term management and storage of wastes. One of our major efforts is the engineering development of a facility to be ready in the early 1980's for the retrievable storage of solidified high level waste from the commercial nuclear power industry. This facility would provide for surface storage based upon proven technology. Proposed methods for using geologic formations for eventual permanent storage are still being evaluated. From studies currently underway, we are hopeful that in the long-run the very high energy neutrons available from nuclear fusion plants can be used to deactivate by transmutation many of the most troublesome and long-lived radioactive waste products.

Fusion, the process by which energy is generated in the Sun and stars, continues to look attractive as a power source for future commercial application. Successes in recent tests of the physics principles upon which fusion rests have convinced us that it is time to move another step forward, to larger experimental systems. These systems will be of a sufficient size to begin to test some of the engineering features of future reactors, while testing the remaining physics principles in a definitive way. The next generation devices will operate in the 1975-78 time period, followed by the first projected Fusion Test Reactor (FTR) around 1980. The FTR will be designed to produce thermal power of tens of megawatts but not electricity. Experimental Fusion Power Peactors (EPR I, II) producing some electrical power would be built during the 1980's, and the first Fusion Demonstration Power Plant would operate in the mid to late 1990's as a commercial prototype.

The AEC has smaller, but vigorous, programs on energy transmission, energy storage, and geothermal energy technology; and on in-place recovery of energy resources including coal gasification. A program on the application of underground explosions is also continuing aimed at oil recovery from oil shale and stimulation of natural gas.

AEC estimates suggest that 20 million electrical kilowatts could be attained from geothermal sources by 1985 if significant technological advances, industrial participation and adequate funding is provided. The AEC FY 1975 budget request contains $10.7 million for this research and development plus $1 million to begin detailed design of a 10 MWe demonstration geothermal power plant to operate in 1978. This plant would be the first of several plants demonstating production of energy from various types of geothermal souces.

In the U.S. today the supply of natural gas is already short of current demand. It appears that we are already close to the peak of natural gas recovery by conventional production techniques. In light of this situation the AEC is instituting a program aimed at producing synthetic gas by in-place coal gasification. The concept is to use chemical explosives to fracture coal at depths of 1000-3000 feet. Oxygen and steam would be used to convert the coal to a gas mixture which will be recovered at the surface and converted to synthetic gas. ($4.5 million is being requested in FY 1975 to initiate this program.) This program is significant in that it has the potential to utilize the largest fraction of U.S. coal reserves which are too deep to mine economically.

In the area of energy storage, a principal effort is the development of high performance batteries for off-peak electrical energy storage and for automative power systems. It is hoped that this development will lead to manufacture of lithium/sulfur prototypes by the end of the decade and construction of a battery test facility on a utility network in about 3 years.

Superconducting magnetic energy storage and energy storage by the production, storage and reconversion of hydrogen to electricity are also being pursued in AEC programs.

In the area of energy transmission, the AEC has programs on the development of underground superconducting cables. These cables would be more efficient and less expensive than conventional cables for high capacity transmission. Studies indicate that superconducting transmission lines are technically and economically feasible. The AEC program is aimed at developing optimum sytems components, demonstrating high reliability, and developing cooperative programs with industry aimed at commercialization. Discussions are being carried on with industry in hopes of installing a demonstration superconducting cable in a utility system in 1980.

As you can see, the Atomic Energy Commission is playing a key role in both near-term and long-range solutions to the energy shortage which confronts us. About half of the funds for Federal energy research and development projected for FY 1975 will be managed by the AEC. The largest expenditure is for the development of the Liquid Metal Fast Breeder Reactor and other programs for nuclear fission applications, including radioactive waste management, reactor safety research and uranium enrichment. The nuclear fusion program is being pursued vigorously, aiming at a demonstration power plant in the late 1990's. In other areas, such as geothermal and coal gasification, the AEC program is a relatively small, but vigorous element in a larger Federal effort. In solar energy research, the lead responsibility is with the National Science Foundation with proposed expenditures of $50 million in FY 1975.

Table I. ER&D Program and Budget Recommendations
($ Millions)

Self-Sufficiency Tasks	ER&D Programs, FY 1975-1979			Federal ER&D Budget		
	Total Required	Private Expected	Federal Recommended	FY 1974 Planned	FY 1975 Recommended	FY 1975 Presidential Budget
1. Conserve Energy and Energy Resources	4,940	3,500	1,440	62.3	166.2	115.7
2. Produce Oil and Natural Gas	4,960	4,500	460	19.5	51.7	41.8
3. Produce and Use Coal	5,175	3,000	2,175	167.2	405.0	426.7
4. Produce Nuclear Energy	5,340	1,250	4,090	517.3	731.7	724.7
5. Use Other Sources, Pursue Future Prospects	2,085	250	1,835	123.0	217.5	323.1
6. Environmental Control..	-	-	-	-	-	178.5
Subtotal, Direct	22,500	12,500	10,000	889.3	1,572.1	1,810.5
7. Supporting, Environmental Research			650		105.9	133.7
8. Supporting, Basic Research and Manpower Development			350		48.0	82.3
Total	22,500	12,500	11,000	889.3	1,726.0	2,026.5

Table II. Federal Energy Research and Development Program
(Millions)

Programs	Total Federal			Total AEC			AEC % of
	FY 73	FY 74	F Y 75	FY 73	FY 74	FY 75	FY 75 Total
Conservation	32.2	65.0	115.7	1.5	3.7	15.6	13
Oil, Gas, Shale	18.7	19.1	41.8	7.5	4.8	4.7	11
Coal	85.1	164.4	426.7	0	0	4.5	1
Environmental Control	38.4	65.5	178.5	0.3	1.2	2.5	1.4
Nuclear Fission	406.5	530.5	724.7	405.6	529.3	720.6	99
Fusion - Magnetic Confinement	39.7	57.0	102.3	39.7	57.0	102.3	100
Fusion - Laser	35.1	44.1	66.3	35.1	44.1	66.3	100
Solar	4.0	13.8	50.0	0	0.6	0	-
Geothermal	4.4	10.9	44.7	0	4.7	12.7	3
Systems Studies	7.2	17.3	30.0	0.3	1.0	3.0	10
Other	0.9	11.5	29.8	0	0	0	-
Total Direct R&D	672.2	999.1	1810.5	489.4	646.0	932.8	52
Additional Funds for Supporting Programs:							
Environmental and Health Effects			133.7			16.2	12
Basic Research and Manpower Dev.			82.3			20.6	25
Total, Supporting			216.0			36.8	17

Table III: AEC Nuclear Fission R&D
($ Millions)

Programs	FY 1973	Total Federal FY 1974	FY 1975
LMFBR	253.7	357.3	473.4
Other Breeders (GCFBR and MSBR)	5.6	4.0	11.0
HTGR	7.3	13.8	41.0
LWBR	29.5	29.0	21.4
Reactor Safety Research	38.8	48.6	61.2
Waste Management	3.6	6.2	11.5
Uranium Enrichment	50.3	57.5	66.0
Resource Assessment	1.9	2.2	6.3
Other (including Advanced Technology)	14.9	10.7	28.8
Total, Nuclear Fission	$405.6	$529.3	$720.6

NATIONAL SCIENCE FOUNDATION ENERGY RESEARCH AND DEVELOPMENT PROGRAMS

by

Dr. Alfred J. Eggers, Jr.
Assistant Director

I think it is particularly fitting that the American Defense Preparedness Association should have an interest in the most essential nature of the word "energy." When all is said and done, we are going to go where our energy will permit us to go and, if we don't have the energy to do it, we are going to be at a real disadvantage, whether it is military defense issues that are at stake or moving ahead effectively with our economy. The subject that I'm going to discuss is the role of the National Science Foundation in contributing as part of the Federal team to meeting these new challenges that we are facing in the energy business. The Foundation, as the Chairman of the Session pointed out, has a number of responsibilities that relate to dealing with the energy problem. Historically, of course, the basic role of the Foundation has been to support basic research in the United States. Interestingly enough, the creation of the Foundation was as much as anything, as I am sure many of you know, a product of experience gained in World War II, when Vannevar Bush had the Federal leadership for defense research and development. Out of that experience, he concluded that there should be a major continuing Federal effort to support basic research in the country so that, when serious challenges arose, the likelihood of our having a sizeable body of knowledge to draw on to deal with those challenges in applied research and development and operations would be substantially enhanced over what it had been in the past. So it is no surprise that the energy-related basic research supported by the Foundation over the years has been quite sizeable and at the present time equates to something over a hundred million dollars worth of effort. I'm speaking of the large body of materials research that relates to dealing with energy problems, research, and basic areas of fluid mechanics, chemical kinetics, etc.

It seemed to me, with the short time that we had to talk about it this morning, that it might be useful if I focused my attention on a relatively new program in the Foundation – the one described by the Chairman as RANN (Research Applied to National Need), which is responsible for the major effort supported by the Foundation in determining where we should support problem-focused research which, of course, has a very high level of applied research involved in it. My first slide shows the rationale used in terms of the various phases of research, those phases that we believe we should support. You will note there that, within the framework of the charter of the Foundation, we involve ourselves with supporting the research in phases 0 through 2, where phase 0 is advanced research and systems analysis; phase 1, systems definition and subsistence experiment; and phase 2, the so-called systems group of concept experiments. This does not relate exactly on a one-to-one basis. We do not involve ourselves in phases 3 or 4 – that is not consistent with the charter of the Foundation and is initiated, quite properly, to be the responsibility of the user community, whether it be other mission Federal agencies or industry, or state or local governments. I might add in this connection that we do, in some programs I'm going to speak about, have close working relationships with DOD, where DOD is clearly the user and we are the supporter of the basic and applied research that may have application to meeting some of their mission needs.

I'd like to give you a little more specific description of how we decide whether or not we should support a given type of problem-focused research in the RANN program as a part of the Foundation. The basic criteria that we employ included consideration of the importance of problem elimination, the payoff to be realized in relationship to the anticipated cost of dealing with the problem, the leverage of science and technology on a problem – and, while I'm not going into any aspects really of our undertakings other than energy – we are involved in many other problems where social economic considerations and legal considerations, etc., play an important role.

As you all can appreciate, it does not always follow, as one looks at problems which include considerations of those factors, that science and technology would really have any role to play. Another important consideration is the capability of various institutions to mount an effective research effort. And always, of course, we ask ourselves, is there a qualified need for Federal action on the problem or should it be left to the private sector, or state or local government? As far as a specific role in National Science Foundation, as far as RANN is concerned, the question is whether or not we should pick up the ball and carry it, so to speak, for the Federal Government. In general, we say that there may be a firm basis for an affirmative answer to that question. Should we carry the ball for problems that fall between or outside areas of responsibility of other mission agencies, problems that span the areas of responsibilities of other mission agencies? Our involvement in solar energy is perhaps an outstanding example of an undertaking that we address ourselves to because there was no other agency dealing with the problem several years back. In the case of problems that span the responsibilities of other agencies, we have among the strongest, if not the strongest, energy systems program in the Federal Government at the present time and the reason is that it, too, spans the responsibilities of other agencies; and then problems which cover a longer range and special needs of other agencies; and finally, problems uniquely suited for treatment by research teams that involve combinations of industry, university, national laboratory, and nonprofit organizations. Well, these criteria are applied regularly to the issues that are brought before us as problems and to the question of whether or not we say we should deal with the subject or possibly deal with it.

Generally speaking, at the beginning of this program some three years ago, we determined that our focus should be in three major problem areas – in particular, the energy problem. The other two problems are the interactive relationships with environmental problems and, finally, productivity problems in both the public and private sectors.

Now all I am going to deal with here today is the matter of energy. I am sure you are all well aware, or were indeed even before this meeting was convened, of the national need to use our depletable energy resources more wisely. There is nothing that has happened in recent times that has affected matters other than to increase the urgency of this need. To relieve matters, we believe in innovation and imaginative research and alternative resources to meet our energy requirements.

It is on the basis of that issue, which is one of longer standing than is more recently addressed by the newspapers, etc., that this energy research and technology program in RANN has been the largest single program in the whole RANN effort. To understand the overall scope of RANN energy research and technology effort, I think it is worth taking a look at the general circumstances of energy production and use in the United States. I think you are all pretty well aware, for example, that the overall efficiency of the national system is now running approximately 50 percent.

Our program in this overall energy system is directed first toward those areas in which major improvements are possible through making better use of resources or introducing new capabilities. Reducing the losses that appear at many places in the system also figures importantly in our thinking. For example, we are working, through the introduction of new technology in solar and thermal energy, to minimize the growing dependence on foreign imports, and we are supporting efforts to make better use of America's energy resources, especially coal, and obviously in close cooperation with the Office of Coal Research. We are working to improve efficiencies through activities in the area of energy conversion and storage, and, likewise, we are addressing ourselves to some major issues in energy and fuel transportation and, then again, in the overall energy systems.

I would like to highlight very quickly some of the more significant aspects of progress in this work and some of the thrusts we see in our efforts as we move into fiscal year 1975.

First, the case of solar energy. We have outfitted some four schools with experimental solar heating systems. The school at Timonium, Maryland, which is on the chart, became operational on March 1, and this particular school has some 5700 square feet of collector area and contains three major wings of which the heating requirements of one wing will be supplied by that collector system except for perhaps the months of December and January when the total capacity of that system will only meet about 50% to 60% of the heating requirement. A key element of any solar system is storage, of course, and you can see the outlines of a heat storage reservoir which holds 15,000 gallons of water.

In addition to the Timonium School heat augmentation system, which is strictly an experimental one, we also have one which is going on line in late March – the Grover Cleveland School in Boston. There is considerable similarity between the two systems but, in fact, the collectors are quite different. The collector system at the Timonium School is a honeycomb-type structure, whereas the Grover Cleveland School has a flat-plate-type structure. In this application the outer surface is lexan, whereas at Timonium the outer surface is glass and it is interesting that we are not exactly working with new technology here. For the practical applications we have in mind, these systems – the one in the Boston school and the one at Timonium – are employing collectors which have relatively few hours of test in the laboratory and, as a matter of fact, the real lifetime tests of the systems will indeed be done on these two installations, and the lifetimes of these systems are indeed very key questions. For example, in the case of lexan – how long it will operate before discoloration sets in and reduction in response of the collectors starts taking place we are not at all sure.

There are two other schools that will be involved: the high school in Warrenton, Virginia, and the Northview School in Minnesota. They differ from the installations I just described in that the collector systems will be located on the ground.

This brings up an important point. We are not only getting some initial experimental data on the real life environment, and the performance of the collectors, and the other elements of the total system, but we are going to an aspect which involves the retrofit application of these systems to existing schools. None of these schools were built to take solar heating and cooling equipment initially, and we are particularly interested in this retrofit issue. If the technology moves ahead as we think it can, and if the potential for widespread application from the standpoint of the readiness of the technology is achieved at a relatively early time, then the potential for that application is much greater if we can move into the retrofit field as well as into new construction.

Let us move on now to studies in mobile solar laboratories which are ongoing at the National Bureau of Standards where a laboratory is in the process of being fully calibrated. This mobile laboratory was built with support by the National Science Foundation and by the Minneapolis Honeywell Corporation. In effect, the laboratory is two things – it is a mobile weather station and, of course, a station for measuring solar intensity. It is in the solar data that we have particular interest; i.e., solar flux as a function of local climatic conditions and as a function of geographic location in the United States. Likewise, the laboratory is a test bed for heating and cooling systems as well as for collector systems. This collector system is about 625 square feet and is in fact identical, in terms of the technology involved, to the collector system that is employed in the Northview School in Minnesota. We will be moving this laboratory to the locations of these school experiments because it is a highly calibrated piece of equipment. We can then get a cross-check against performance of the school installations. In addition, when it completes that tour, the laboratory will go back to the Honeywell plant in Minnesota and be outfitted with advanced cooling systems, then it will proceed through the summer in a circuit through the East Coast, the Southwest, and up through the West Coast to pick up performance characteristics of these various cooling systems as a function of local environmental considerations such as humidity, etc. We will also pick up the solar insulation data as the laboratory goes along the tour. The largest effort to pick up the solar insulation data, as the laboratory goes along, will be carried out with the support of the National Oceanic Atmospheric Administration (NOAA) and, through NOAA, by the various weather stations throughout the United States. (My picture of this laboratory shows the internal equipment bays.)

We will leave the discussion of the mobile laboratory and go to other matters which we want to talk about very briefly. We are sponsoring studies at the present time in the potential of solar heating and cooling, and they are coming to a conclusion in about two months. The studies are under the direction of General Electric, Westinghouse, and TRW Systems. These studies are directed to establishing operational requirements for solar heating and cooling, to identifying cost-effective approaches, to assessing the social environmental impacts, to analyzing the potential proof-of-concept experiments, and to broadening strategies for achieving acceptance by financial and architectural organizations, builders, and owners. Preliminary results of these studies indicate, and it's not too surprising, that solar energy systems will be most effective in the northern area of the United States for heating, in the middle regions for both heating and cooling, and in the southern regions for cooling alone.

Now let me complete my discussions of solar heating and cooling by showing a chart on criteria against which we are operating' and I just want to call your attention to the fact that we are moving aggressively toward these proof-of-concept experiments in FY 1976. We are thinking in terms of some 15 to 25 various types of building structures which will be fully equipped with heating and cooling systems. They will be buildings ranging from single-family home dwellings to large office buildings, factories, etc. And I might add that, as one gets into the solar heating and cooling application to buildings, the degree to which performance requirements vary with the type of structure and with building location throughout the United States is amazing.

Let's move to another aspect of solar energy – the solar-thermal conversion area. By this, we mean the use of solar energy to bring a liquid to boil and thus drive a turbine to generate electrical power. We also recognize, of course, space heating as being a potential byproduct of this process. We are proposing a 3/8-scale parabolic trough collector on which the design has been completed, and it is now fabricated to initiate solar-thermal experiments. Another solar-thermal project is planned for FY 1975 and this is the design of a central receiver that will heat the working fluid to about 1000°F to produce electrical power. This project includes the design fabrication and test of heliostat reflectors which are distributed at the ground level and the bench-model central receivers and central storage subsystems.

Significant emphasis is also being given to the use of solar cells such as those used in space to generate electricity. This is a very formidable challenge, particularly an economic challenge, since it has been our estimate that we must reduce the cost of producing these cells by a factor of somewhere between 100 and 1000 if they are to be economically competitive with other sources of energy for any widespread application.

One dramatic improvement in the solar cell is in the production of single crystal ribbon production which has been achieved in the joint Harvard University – Tyco Laboratories project. The ribbon in the center of a coil has been drawn to about 12 inches in length and one inch in breadth. The performance of these ribbons is close to 80% to 90% of the standard-type solar cell in terms of milliamperes per square centimeter of ribbon area, so we are not losing much efficiency. The estimate is that, if this edge-fed single-crystal ribbon really pans out – as it looks from early laboratory tests – we can get anywhere from a factor of 10 and more in cost reduction. It will obviously take more than this improvement to reach the factor of 100 reduction which I mentioned earlier and which we must have.

Here is a real fun project which I always like to talk about regarding another solar energy source. It is the energy of the wind. We include wind energy under solar energy because the actual energy source driving the wind is primarily the sun. What we are doing is taking a hard look at the windmill again. That should not be too surprising, any more than the revival of interest in coal. They are both old and venerable sources of energy. Anyway, what I want to mention is that we now have an aggressive program moving in the wind energy area and it looks like it has the potential for a very early payoff. In this case, we are working very closely with the NASA Lewis Research Center in Cleveland, Ohio.

One interesting approach is an experimental wind energy electrical-generating system which has a rotor about 125 feet in diameter mounted on a tower more than 100 feet high. It is designed to generate about 100 kw of electrical power at a wind velocity of 18 miles an hour. We are pushing ahead on this large-scale experiment with the expectation that by May or June of 1975 the equipment will be in on line for extended experiments. These are not systems which you just throw up in a hurry. They are very large scale and there are major problems associated with the blade fabrication in particular. The gear train is, of necessity, a step-up type from 40 rpm for the blade to about 1800 rpm for the power-generating armature. And, again, the question is, can we get the cost down on this type of equipment? This will be one of the big challenges – the gear-train system, the generator itself, getting the cost of blades down and, likewise, getting the cost of the tower structure to an economic level. In the case of the blades, the composite structures are going to be looked at very hard to determine whether they really have efficient application.

We are looking at a variety of techniques for getting constant voltage and constant frequency output from wind-generator designs, and one such design which seems to offer promise is being looked at very aggressively by the University of Oklahoma.

My next energy source is bio conversion – the generation of energy from organic materials. In a very real sense, this is the oldest form of energy, since burning wood is an example of such energy sources. We are looking at a spectrum of possibilities now ranging through energy forms generating particular types of force, if you will, with high Btu per pound per year of output. This growing rate figures importantly of course as the Btu per pound is something you have grown. We are looking from direct growth on the one extreme to the limit of the other extreme of potential of generating hydrogen from green algae using a photo-synthetic process and the enzyme hydrogenase to create hydrogen from the bio process. That has now been accomplished on a laboratory scale and may soon be a major breakthrough in a so-called hydrogen economy which many of us talk about and which certain people are most enthusiastic for.

Another area which is being looked at vigorously is the generation of methane from municipal solid wastes. One experimental setup consists of an anaerobic digester made by Dynatek. We propose to run experiments next year which will prove the concept. The most important issue or uncertainty is in the anaerobic digester – can it be operated for long periods with high methane output, or will we be spending the most of our time in depoisoning it or something of that nature? We don' know – we have to learn about that.

Now let me turn to another important source of energy – the use of solar energy as it is captured in the oceans. There are various ways of doing that. One of the oldest ideas (and today one of the most attractive) is to exploit the ocean thermal radiance; that is, from relatively high temperatures at the surface to the lower temperatures which occur at 1000 to 2000 feet down. The so-called Clod system, which was tested back in the early 1920's, would put out something like 12 kilowatts for several days, and is an example of its potential. There are many, many problems that are associated with such energy systems. However, it is important to remember with that system you not only have your collector provided by nature but you also have storage provided by nature. The real issue then is, how do we tap the energy reserves that have been collected and stored?

There are a number of efforts under way at the present time to pin down the most promising concepts; one is being investigated by Professor Hieronymus of Massachusetts, one of the leading thinkers in this area. His work has produced about a 400-kw machine. He has devised a long, deep center pipe which goes down to the low temperature source to extract cold water from the lower depths and there is a major heat exchanger at the surface. This is an area in which the National Science Foundation is working particularly close with the Navy. For obvious reasons, the Navy has a special expertise in technologies of this type as well as parochial interest in exploiting the power output of the system if it can indeed be developed to economic and effective sources. The deep water potential is thought of as about a 400-megawatt energy source which makes it a very attractive concept for power output from the ocean thermal-type systems.

This pretty much summarizes what I had wished to emphasize on the various types of energy for national needs, with the sun as the source. My very long range projection is that the potential of solar energy could supply as much as half the total national energy needs. With aggressive research and development programs to prove out and exploit these technologies, this potential might be realized by the turn of the century. The real impact of solar thermal energy exploitation is not expected to be significant until the 1980's.

Geothermal energy is another area of interest now. There is only one operational geothermal plant in the United States at the present time; it is at geysers in Northern California, about 60 to 70 miles north of San Francisco. The plant is now putting out about 450 megawatts or about half the requirement (which runs around 1000 megawatts) of the city of San Francisco. The geysers are projected to reach that level by the 1980's. But that supply is relatively dry steam and is a relatively easy source of energy to tap. The important reserves of geothermal energy are in the hot brines and in the deep earth hot-rock sources. When you get into the hot brines, the estimate is that you may be able to produce tens of thousands of megawatts of power. The steam, as far as we can tell, is not likely to exceed the thousands of megawatts simply because it's not all that available.

Now, just let me touch briefly on a few of our undertakings. One of the big problems is surveying for the locations of geothermal resources. There is a zone of high heat flow that has been discovered by the New Mexico Institute of Mining and Technology under the Rio Grande rift in New Mexico, and this is now a site to design and carry out proof-of-concepts experiments. The Los Alamos National Laboratory, working closely with the United States Geological Survey is moving ahead to see what the possibilities are in tapping a hot-rock resource which is located immediately under the Los Alamos Laboratory. We have, through geophysical tests, now confirmed the existence of a major thermal anomaly near Marysville, Montana, and we are attempting to correlate the gravitational anomalies with the location of the hot-rock source itself (which is referred to by geophysicists as an intrusion).

There is a very close correlation between the gravitational and thermal anomalies. Very high heat rates have been identified at temperature gradients of more than 20° per 100 feet of depth as we move down to the energy source. We believe that resource is some 6000 feet below the surface of the ground and we moved this spring (1974) to drill at the site near Marysville. If, indeed, this is a hot-rock resource, which is our belief even though there is no evidence of steam or water near the surface, we will then have the really big challenge as to how to get the energy out of the source. One of our concerns is that if the rock is a relatively nonporous rock, and that's what we expect, we will have to go into fracturing of the rock strata to get the exposed surface area to the point where we can get high-heat transfer rates to fluids which we will pump down the hole. (Water will be heated to relatively high temperatures.) This whole issue of actually fracturing the rock at these depths to achieve the desired high-heat transfer rate is something that needs a lot of research, and we are only beginning to learn about it. Hydrofracturing and other means of fracturing rock are under investigation. We have a major laboratory that is doing research in that area and that is Stanford University. We use a huge tank in simulating hydrofracturing and the aquifers (or water-rock mixtures) and in studying the heat transfers as a function of the nature of the aquifers' porosity and other physical characteristics.

We are carrying out studies in the Imperial Valley and we have discovered an interesting thing there. There are silicic caps which seem to form over these brine reservoirs and act as containers, if you will, for the reservoirs. Indeed we may end up looking for these so-called silicic caps to identify the presence of the brine reservoirs and then proceed to exploit the site for its energy content as a primary condition for a geothermal site. In FY 1975 we expect to move ahead quite aggressively. We propose proof-of-concept experiments in the hot brines to be followed in 1976 and 1977 in the hot dry rock utilization and then the pressure zones which will parallel the hot-rock exploitation. There is a national target in the geothermal area and that is to achieve the order of 30,000 megawatts of power by the mid-1980's. The way things look, we believe we have a good chance to achieve that goal.

There are many technologies in the geothermal area that have to be considered insofar as working with these brines. We are concerned with effective heat-exchanger systems and turbines where corrosion effects must be minimized. These technologies represent very major challenges.

Let me move on to our other energy resources work very quickly. We are working with advanced technologies in the coal field, primarily with universities. One of the most fascinating of the efforts underway is the so-called coal-plex concept. It's an exploitation fundamentally of Shroeder chemistry; this is the hydrogenation of coal at relatively high temperatures of 800° to 900°C at high pressures. One of the keys is the short exposure time of the coal to the hydrogen which is required if one is to get high yields of methane, toluene, xylene, and benzine. The methane, of course, is the basic fuel while the benzine and other gases are the components of gasoline. Out of this process comes a residue of coke and, here, new fluidized bed technologies are under test to determine the degree to which you can effectively gasify that coal into low Btu gas for pipeline purposes. The progress in this area has been exceptional; the proof of high yields of methane, benzine, toluene, and xylene has already been obtained. By high yields, I am referring to two to three times as much of those products as any other technologies have produced. We have still to overcome some fundamental difficulties in the gasification of the coke to yield that low Btu gas but certainly there is good progress being made in this effort. One of the attractive applications of this so-called coal-plex technology is the inciter generation of energy in the coal mine itself where, literally speaking, you can ship out the gases and have your electrical generating plant located at the time to take the low Btu fuel gas to generate the electrical power. We expect to move the coal-plex effort ahead, plus looking at some advanced technologies for the recovery of oil from this reaction. There are some particularly interesting concepts along these lines being developed at the University of Texas.

Let me now turn to the problems of energy conversion and storage which, of course, are immediately important to us also. One of the issues is to increase efficiencies in these conversion systems, which are running about 40% at the present time. One of the more attractive approaches with the topping cycle is being carried on at the Oak Ridge National Laboratory. They have completed the design and have fabricated components of a potassium boiler furnace module. An advanced power conversion system is possible which utilizes the potassium vapor topping cycle superimposed on a conventional steam cycle. In this system vapor at about 1500°F from the potassium boiler is expanded through a turbine and condensed at about 1100°F. The heat rejected from the potassium cycle is used to produce steam turbine cycles. Through this topping cycle process, the overall thermal efficiency is certainly increased from about 40% in conventional turbines to more than 50%, or perhaps even 55%, with a reduction in waste heat and a reduced fuel consumption for a given power output.

Turning to another area, work at the Argonne National Laboratory and at the Ford Motor Company is progressing toward a technology for advanced high temperature or thermal batteries using either lithium or sodium sulfur. Testing of the full-scale welded lithium-sulfur cell was completed at the Argonne Laboratory. Previous tests of open cells had shown lifetimes of about 1000 hours and recycles of 500 to 1000 hours with no significant loss in battery performance. Research now is going toward the welded or sealed cell phase of activity and we are highly optimistic that we will have a high potential for achieving battery capabilities of an order of magnitude both in energy and in power density over lead-acid type batteries. We think that the feasibility of this compact design and the stable operation of the cell can be demonstrated in the very near future, and we believe that this thermal battery technology may make the electric car a possible alternative that will prove economically attractive. It could also have the potential for electrically powered city buses and in storing electrical energy from power plants to level the load.

In the area of energy and fuel transportation, we are working hard on superconducting technologies to provide low energy losses and high power transmission capabilities. We are really talking now in the 10,000-megawatt ballpark of transmission. Our work to date on superconducting tapes has been successful in reducing by about a factor of five the transmission losses from previous designs. We have a new transmission cable made up of these superconducting tapes, and studies made on Long Island indicate that there are real economic applications of such designs for transmitting these large blocks of power, which were mentioned previously, at the 10,000-megawatt level. We expect this work will expedite electrical transmission systems and power networks as we move into FY 1975. And, likewise, we will be initiating research work on increasing pipeline use and efficiency, addressing special problems in the transmission of such fuels as hydrogen, ammonia, and alcohol.

Finally, just a few points on energy systems. Here our research is directed to learning how and where energies are used in our economy, and to provide information to allow improved national management strategies to be devised. We are supporting substantial research on the effects of increasing insulation in various types of houses in various locations to reduce heat losses. In a particular instance, the work at Oak Ridge National Laboratory, we found that something like 3-1/2 inches of insulation in the walls and 6 inches in the ceiling in new electric homes will more than pay for itself. For example, home owners in Atlanta would realize net savings of $90 per year even after amortizing the installation costs.

Fuel economies of up to 30% could be realized if automobile standards for time to accelerate from a standstill to 60 miles per hour were adjusted from the current time of approximately 12 seconds to a time of 20 seconds. We are also supporting research on the application of improved aerodynamic design on truck bodies to reduce drag and attendant fuel consumption. Not surprisingly, the separated airflow following the body of the truck is a big source of aerodynamic drag and appears as base drag aft of the truck. Studies are ongoing on the use of guide vanes at the leading edges and the aft end of the body to cause the airflow to close around the aft end and hence reduce the air drag substantially. We believe, on the basis of work to date, that by this technique we can reduce truck drag by 20% to 30% at a savings of about one billion gallons of fuel per year and that the cost of the guide vanes will be from $150 to $250 for each truck.

I would like to talk with you about the environmental phases of energy but I see I have already used too much of your time. I want to thank you for the privilege of being here to discuss energy problems.

THE ENERGY PROBLEM AND DEFENSE

by

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I. IS THERE REALLY AN "ENERGY CRISIS"?

For the last year or so, energy has been a major topic of discussion, both in this country and around the world. Limitations on new sales of natural gas, occasional brownouts in the summer, news of political maneuvering over Middle Eastern oil, the impact which environmental regulations have had on the availability of gasoline and heating oil, and the ever rising costs of energy: all these events have sparked concern over the reserves of energy which we can tap and the ability of our nation to continue growing while at the same time preserving our hard won standard of living. Prophets of doom have predicted energy shortages which will get worse before they get better. More knowledgeable energy experts forecast spot shortages, rising energy costs and the need for more efficient use of the energy we have. In any case, there is a problem, a problem which we can and will solve by making intelligent use of the fossil fuels which we have and by moving ahead rapidly on the path to developing new energy sources.

To put the world and national energy situation in perspective, we have to look at a few basic facts which I believe summarize the dimensions of the problem we face as a nation. Then we will have a look at how these facts impact our energy posture in defense.

First of all, is this energy problem something new? Did we get caught by surprise? Definitely not! Energy experts in the government and in private industry have been projecting supply constraints and rising costs in recent years. Energy consumed abroad has been, for many years, a much more expensive commodity than it has been in this country. Research on new energy sources, some of it supported by the DOD, as in nuclear power, has been underway since the early fifties. However, environmental standards adopted in the last few years have added a new variable to the energy equation.

PRESENT NEED FOR ACTION

We have a long term energy problem today largely because the circumstances that had been forecast are now coming together to focus on our need -

> To adjust our consumption levels to match the available supplies of energy

- To permit the price of energy to reflect the costs of extraction and environmental protection

- To improve the efficiency of the ways in which we use energy to cut down on waste.

FUTURE ENERGY SOURCES

From the broad perspective, the basic energy question may be "are the natural sources of energy we have available sufficient to meet our demands?" If we rely on fossil fuels and do not push forward with the development of nuclear, solar and geothermal sources, then the answer to this question is no! Fossil fuel reserves are, after all, finite! But today the important question is not, "are the sources available?" but "are we willing to pay the price to obtain them?" The long-term energy problem in 1974 is primarily an economic problem and to solve it we need to look at both the demand and supply sides of the economic equation.

TRENDS OF ENERGY CONSUMPTION

Demand for energy is going up at a dramatic rate, both in the U.S. and abroad (Figure 1) The reasons are:

- A growing population

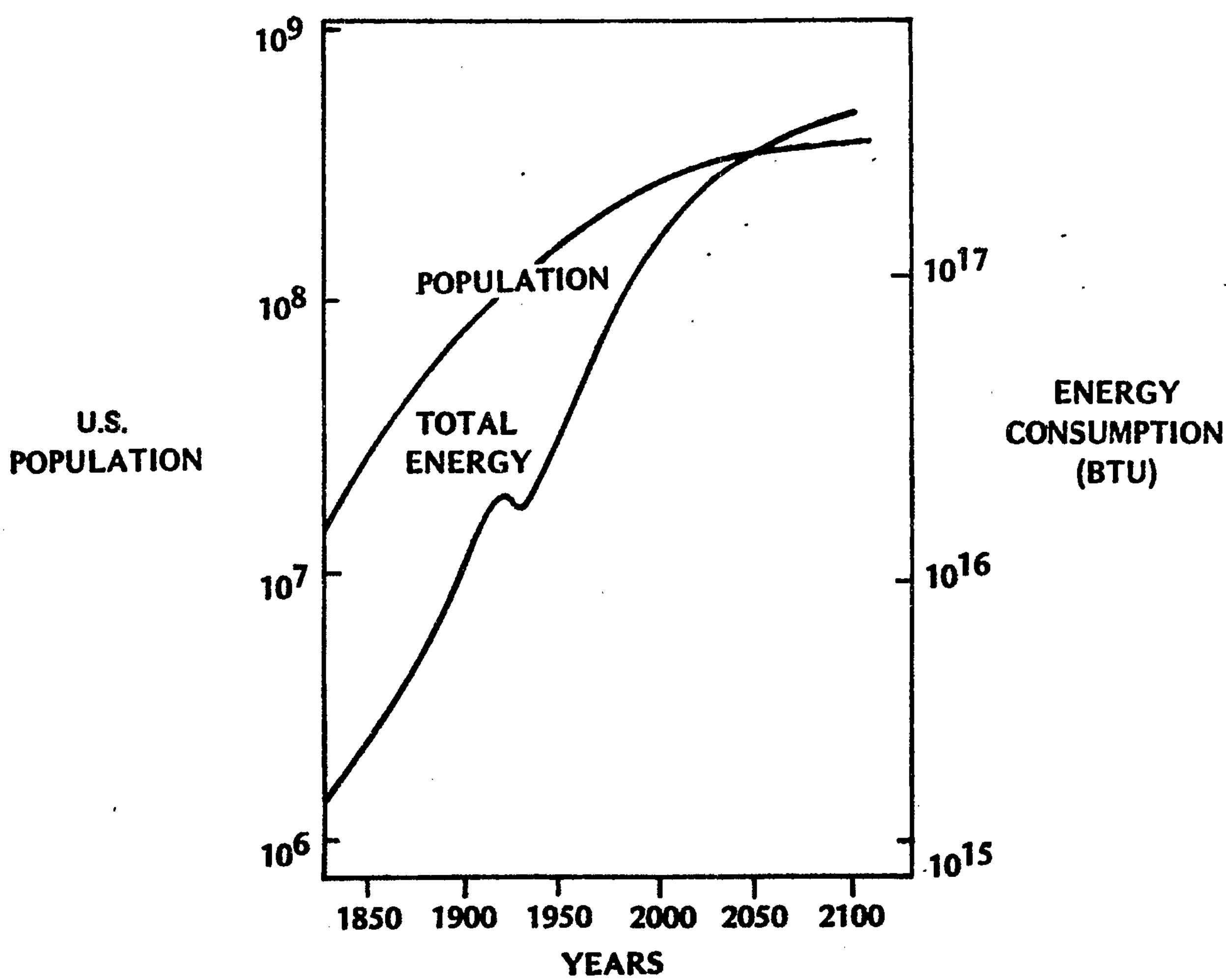
- An increasing per capita consumption

- An ever growing and more energy intensive economy.

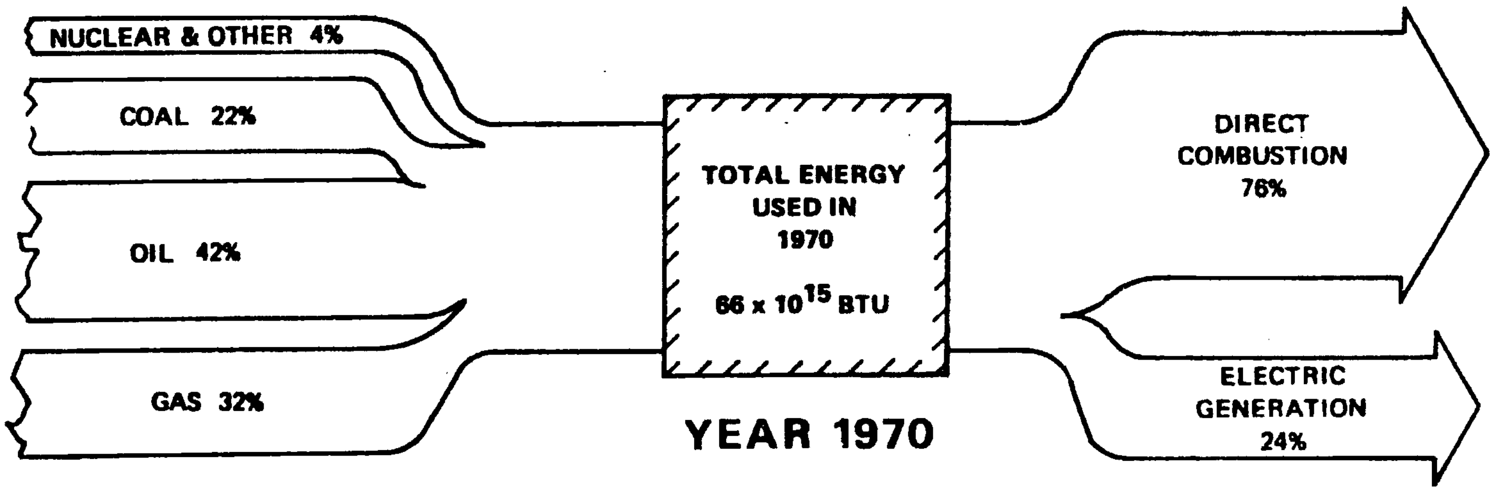
Figure 1 shows that while the nation's population is expected to grow by 50% between now and the turn of the century, our energy demand will double by 1990 and nearly triple by the year 2000. The key point is that energy consumption has been growing faster than the population.

Figure 2 shows that in 1970, all but about 4% of our energy came from fossil fuels--and 3/4 of this energy was used directly: in cars, furnaces and boilers. Looking at the lower portion, we see that by the year 2000 nuclear power may be supplying nearly 1/4, and coal 1/7 of our needs. Some recent estimates indicate that coal may support up to 1/2 of our needs by the year 2000 with oil and gas decreasing proportionately. Nearly half of the projected 150 quadrillion Btu we use will go to electric power generation. As time goes on, we expect to shift even more to an electric economy, with scare petroleum products going exclusively to the chemicals industry. Demand for energy is going up particularly fast in Europe, in Japan, and in the United States. What then about supply to meet this demand?

ENERGY CONSUMPTION IS GROWING FASTER THAN POPULATION



SOURCES AND UTILIZATION OF TOTAL ENERGY



SOURCES AND UTILIZATION OF TOTAL ENERGY

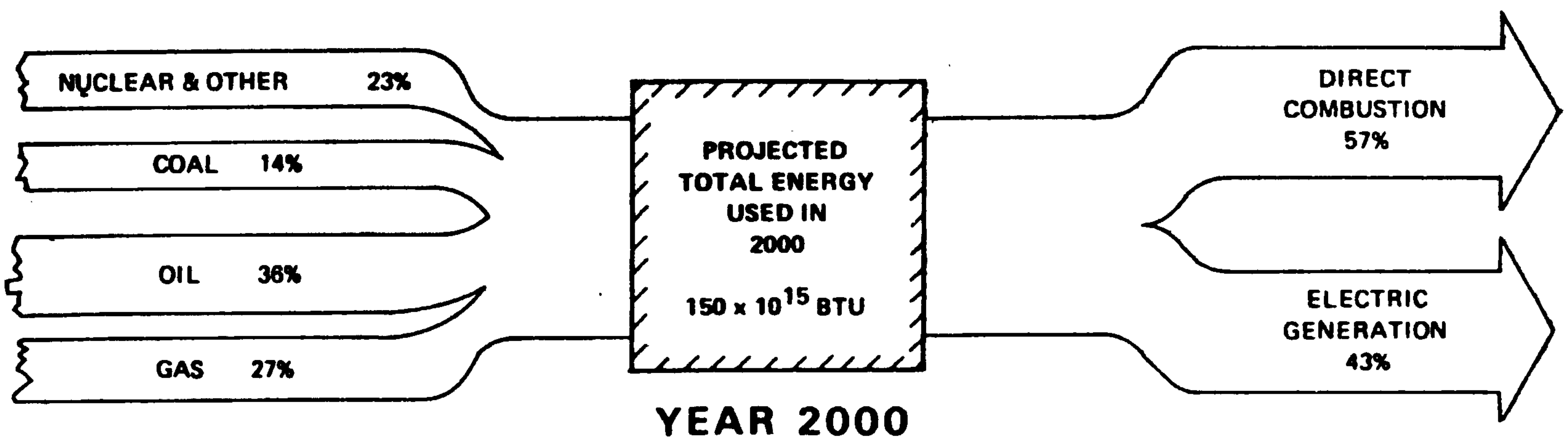


FIGURE 2

ENERGY RESERVES

Though many of the most easily tapped reserves of oil, coal and natural gas have been exploited, there are vast reserves remaining in the ground. With presently known and recoverable reserves, we can meet our needs until the turn of the century and beyond. Our coal reserves alone are estimated to be adequate to meet out total energy needs for 300 years. Roughly a third of our oil came from abroad before the 17 October boycott, and this could increase to 60% by the late 1980's, assuming normal supply is restored in the long term. The security and economic implications of this heavy reliance on foreign oil have been widely publicized. What is not often said is that by blunting the growth of our demand on foreign sources, by tapping our offshore and Alaskan reserves, and by accelerating our efforts to expand nuclear power and to develop processes which convert coal to oil and gas, we could virtually eliminate our dependence on fuel imports in this century. The main point I want to leave with you is that we have the reserves of fossil fuels to get us through the century if we make intelligent use of them, and that in the next century we can count on advanced energy resources to pick up the load if we continue and accelerate the R&D efforts.

ENERGY COSTS

But let me caution you that there will be a price attached to meeting our energy needs. Recovery costs will increase. Primary environmental standards will have to be met. And the price we pay for fuel will continue to rise. Figure 3 shows the recent trend for crude oil prices. Now you and I are having to pay a lot more for our energy needs. The implications for each of us, and for the DoD, is that we have to tighten our energy belts, to use only the energy that we really need.

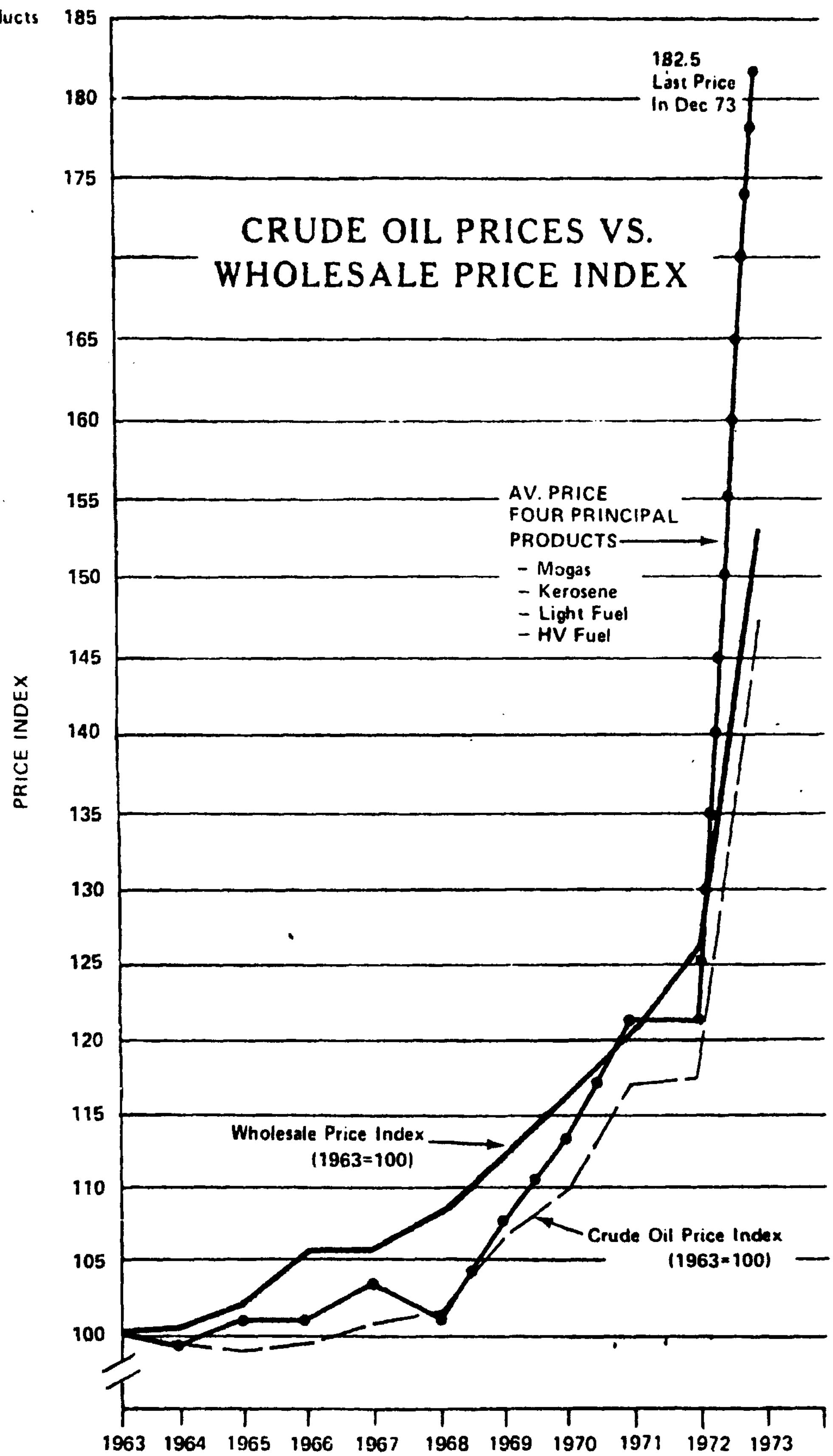
NATIONAL ENERGY PROBLEM--SUMMARY

Before I go on to look at the impact of the energy problem on the DoD, let me leave you with four summary thoughts about the national energy situation:

- At the present rate of growth, the demand for energy will nearly double every 17 years. But we may be able to meet that demand for the foreseeable future if we conserve, if we tap our fossil fuel reserves in the short term, and develop advanced sources in the longer term.

FIGURE 3

Crude Oil Prices & Prin. Products vs. Wholesale Price Index (Index: 1963=100)



- During the next decade there may well be spot shortages of fuel and continued dependence on uncertain foreign sources. With prudent management of our resources, we should be able to meet our needs with domestic sources by 1990.

- The price we pay for energy has increased rapidly, more than doubling as a result of political action as well as increased extraction and environmental costs.

- Because of rising costs and immediate shortages of fuel, the nation and our Department of Defense must learn to be more efficient in the way we use energy and to cut back on demand wherever possible.

II. THE UNITED STATES DEFENSE ENERGY SITUATION

In order to place the energy consumption of the Department of Defense in proper context, it is useful to compare it with the total national energy consumption level. Figure 4 shows that the DoD consumes only 2.4 percent of all the energy used in the United States, and that petroleum accounts for nearly 3/4 of that amount. Electricity accounts for about 17 percent of the total and most of it is purchased from public utilities. Gas and coal are only 7.2 and 3.5 percent of the total respectively.

The average of 637,000 barrels a day of petroleum used by the DoD accounts for less than 3-1/2 percent of the national usage (Figure 5). Prior to the embargo, 50 percent of that was procured overseas. The Air Force consumes more than half of this amount, followed by the Navy with over a third. Though on a national scale the DoD does not use a lot of energy, within the Federal government it is by far the largest consumer, accounting for about 85 percent of government energy use.

TYPES OF DOD ENERGY USE

Nearly half of the DoD energy requirement is consumed in aircraft operations, as shown in Figure 6, and this application accounts for almost 2/3 of the petroleum consumed. Installations will account for almost 40 percent of our energy consumption in FY 1974 and it is estimated that by 1979 this percentage will increase to the point that facilities and aircraft energy requirements will be almost equal.

Much of the DoD petroleum requirement is for JP-4 jet fuel. This fuel is produced from a naptha-based feedstock which is also heavily used by the petrochemical industry. As a further point of interest, the DoD jet fuel consumption in FY73 was equivalent to about 27 percent of the total domestic consumption - now 40% - so in this area DoD requirements have a significant impact on the national scale.

The nation as a whole imported only about one third of its petroleum in 1972, but until the recent embargo, the DoD procured nearly half of all its petroleum from foreign sources, primarily for overseas use. These facts point out very clearly why petroleum is of such critical importance to the DoD and why DoD requirements, although apparently minor from a national viewpoint, are particularly sensitive to the stability of foreign supplies of petroleum.

TOTAL DOD ENERGY (EXCLUDING NUCLEAR)

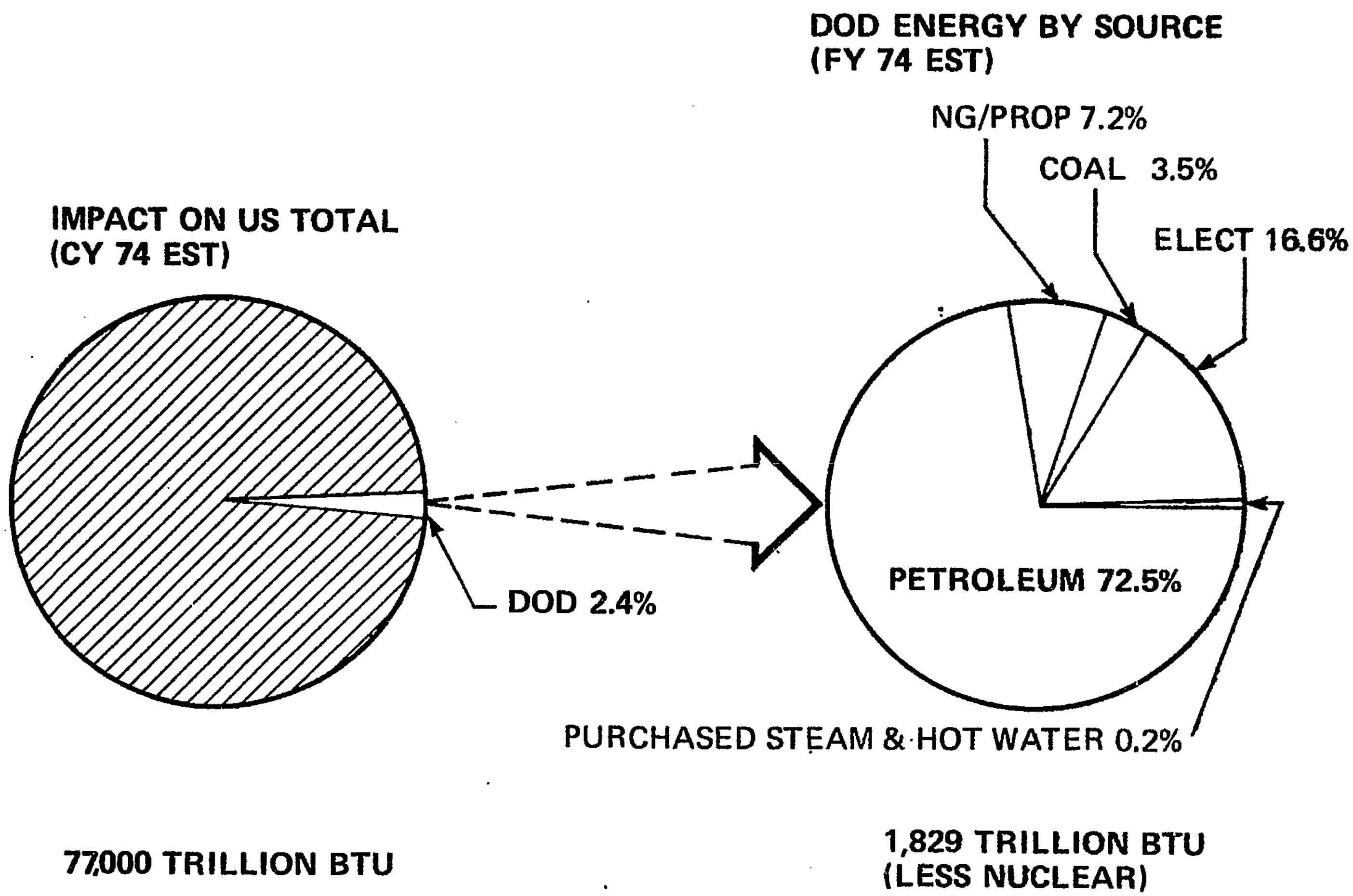
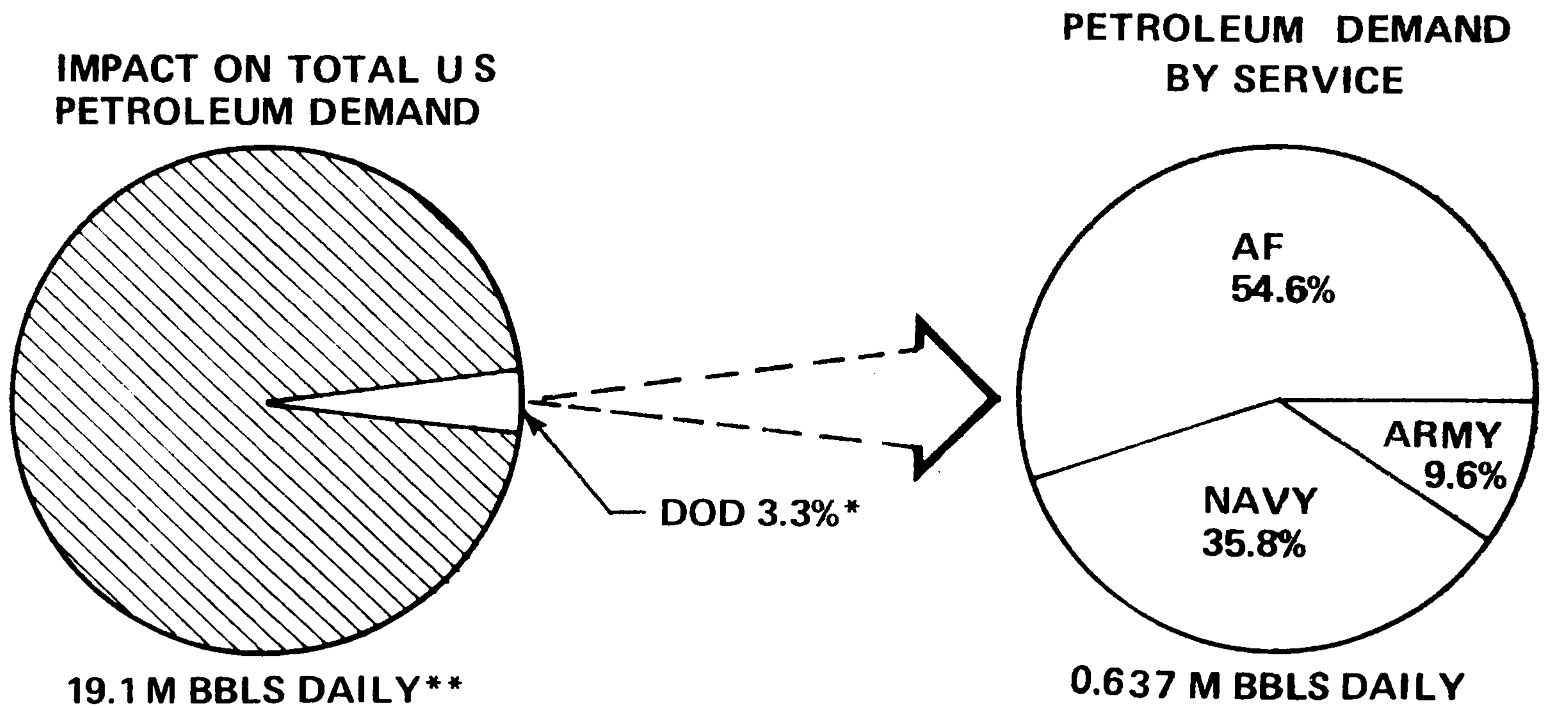


FIGURE 4

TOTAL DOD PETROLEUM ENERGY DEMAND
(FY 74 EST)

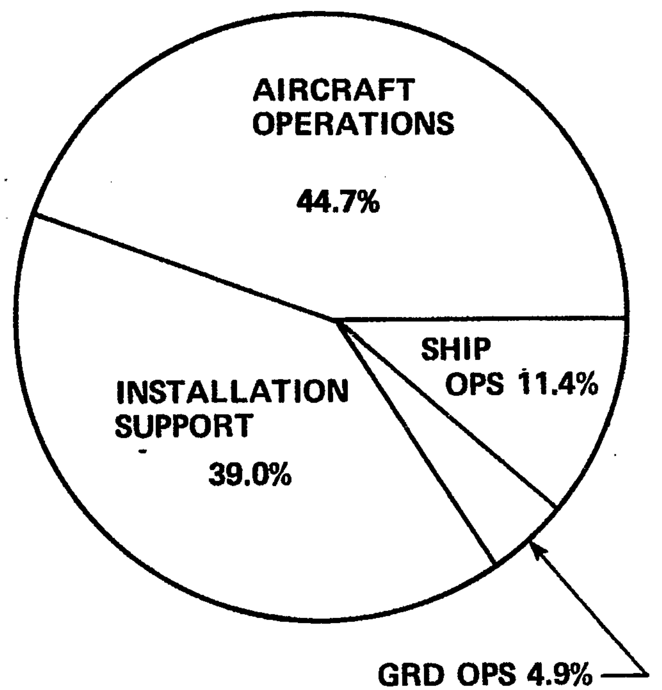


*50% PROCURED FROM FOREIGN SOURCES PRIOR EMBARGO
**FEO FORECAST FOR CY-74 (2 JAN 74)

FIGURE 5

DOD ENERGY DEMAND
(BY OPERATIONAL FUNCTION)
(FY 74 EST)

TOTAL ENERGY



PETROLEUM ENERGY

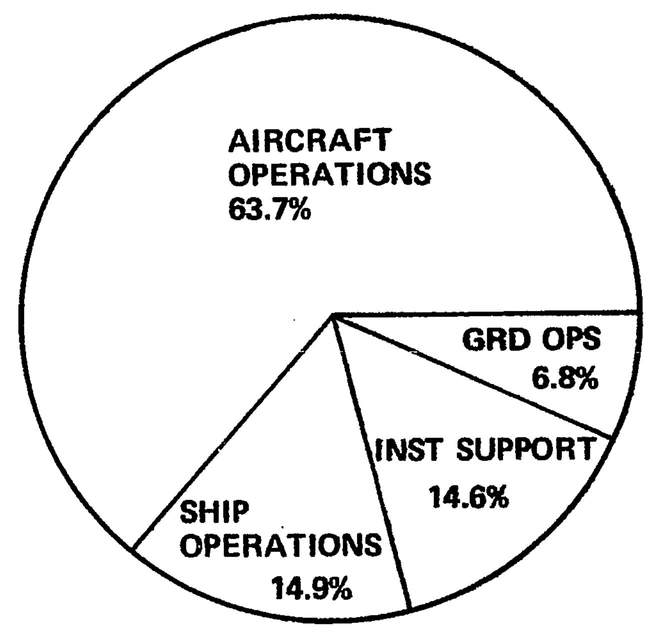


FIGURE 6

ENERGY USE IN MOBILE SYSTEMS

As we saw from Figure 6, mobile systems account for over 60% of all the energy consumed by the DOD and over 85% of all the petroleum consumed. It is therefore essential that we devote our greatest attention to ways in which we can improve the efficiency of energy use in mobile systems while still accomplishing our mission.

It is well known that fuel consumption increases significantly with increases in cruise speed. This suggests possible fuel savings through operating at economical speeds. The argument that is given for reducing automobile speed on the highways for better gas mileage holds for aircraft, ships, and ground equipment as well, throughout the Department of Defense.

Similar logic compels us to minimize all possible usage of those vehicles while maintaining our total readiness. Each of the Services has already devised innovative ways to decrease the amount of energy consumed while retaining all vital mission-oriented programs and activities. For example, the Air Force has introduced a number of measures to cut down on energy use in aircraft operations:

- Reductions in startup time and the shut down of nonessential engines after landing and during taxi.

- Optimizing cruise altitude and reducing low-level flying speeds.

- Increased use of simulators and ground testing.

- Improved refueling operations.

As we become more experienced in thinking about energy and mission together, we will certainly find additional ways to reduce our level of energy consumption.

LAND-BASED FACILITIES

Next, let's turn to the second major area of use, our land-based facilities. Because they are such significant users of energy, it is clear that facilities must be of major concern to an enrgy-conscious DOD. The OSD has for a long time been very concerned with energy use on facilities, and has developed a series of guidelines and standards for conserving energy. In addition, all the services have had a conservation program of sorts for a number of years now. A considerable amount of austerity in base maintenance, utilities, and soforth has existed merely because this is the lowest priority in appropriations, and the first area to receive cuts.

On a more positive note, the DOD Construction Criteria Manual has been recently updated. Building specifications have been made much stricter and should lead to significant conservation of heating and electrical energy. The specifications on air conditioning units have been tightened, and only the most efficient types will even be considered for purchase. In this manual are also found operating instructions for heating, air conditioning, and appliance units.

Following the lead of the GSA, the services have adopted energy saving practices not only in GSA buildings they are temporarily occupying but also in their own buildings. These practices involve a common sense approach to conservation through daylight room-cleaning, higher thermostat settings on air conditioners, and turning off unused lights and appliances.

A recent DOD instruction has formalized heating plant design for reaching the new goals set in environmental pollution standards. A fortuitous by-product of this effort has been the saving of Btu's through increased efficiency.

Recently, the DOD has requested that bases with power plants have a 30-day backup storage capability on their installations to avoid short-term fuel shortages.

In the policy area, a DOD memorandum dated 1 August of last year directs that life-cycle cost estimates for new construction use energy costs which are twice the FY 1972 average. This will ensure a more realistic appraisal of these costs as they are projected into the future.

Last, but not least, in recognition of the increasingly critical energy situation as regards petroleum and natural gas, the moratorium on boiler plan conversion from coal to oil or gas will continue in effect. It may even be necessary to convert some plants back to coal.

FUEL PROCUREMENT PROBLEMS

Now, a few words on our fuel procurement problems. During July, August, September, and October last year the Defense Fuel Supply Center experienced difficulties in procuring fuel for your use. These problems concern both availability and pricing. Serious spot shortages appeared in various geographic areas. As an example (Figure 7), in the West Coast area the shortage of JP-5 contract coverage as of October 1973 was over 40 percent of the total requirement.

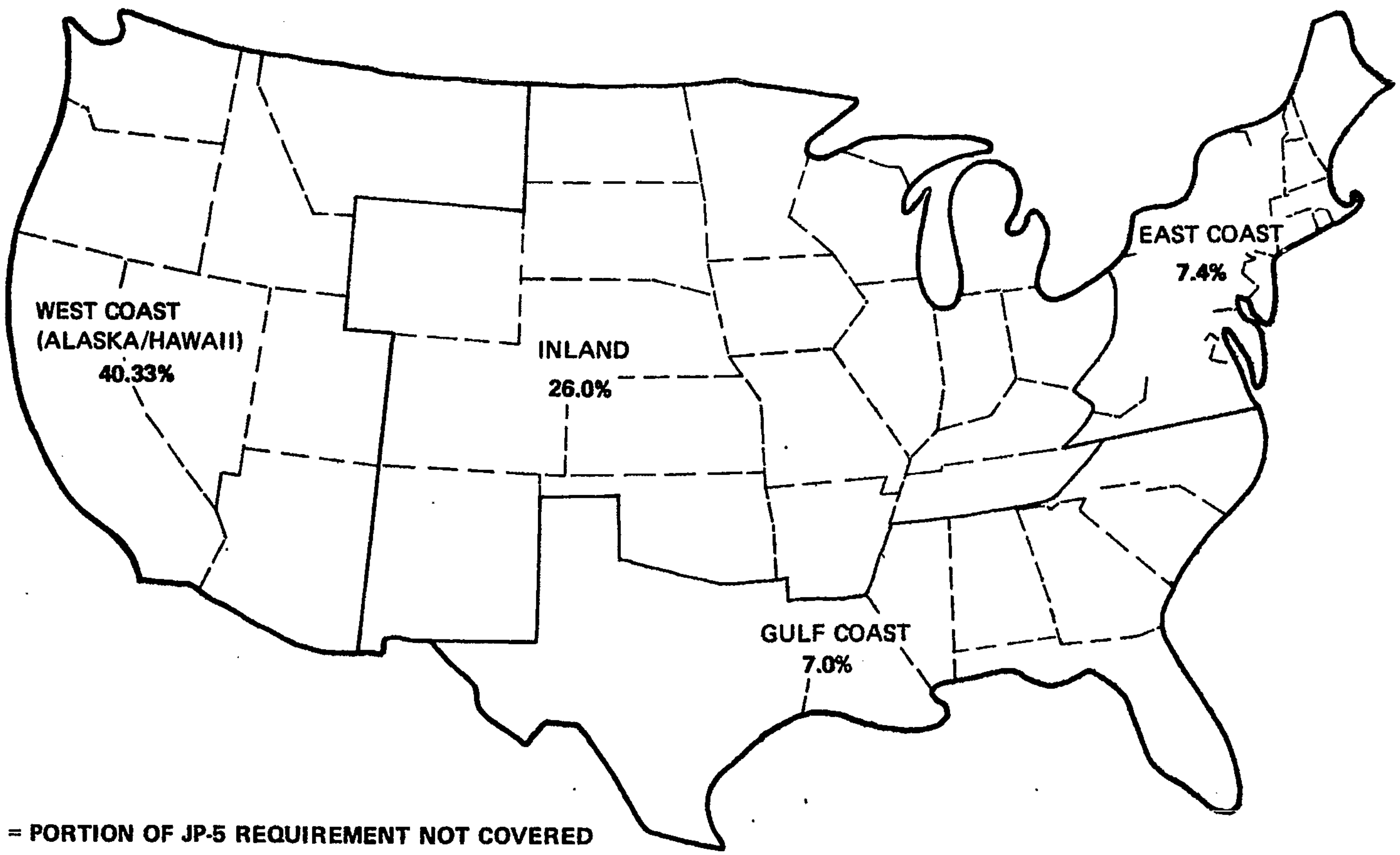
As a result of these developing problems action was initiated in September 1973 to obtain priority allocation through the provisions of the Defense Production Act. Subsequent to the oil embargo in October the Department of Interior approved the priority allocation of 19.7 million barrels of petroleum products for November and December 1973. This amount was later reduced to 19.1 million barrels and the delivery period extended to preclude hardship conditions arising from this action. Product delivery was 67 percent complete as of 25 January 1974. The allocation granted for the first three months of 1974 as well as subsequent priority allocations will be made in accordance with the Petroleum Allocation and Price Regulations. For the third quarter FY 74, the DoD allocation is 637,000 barrels per day.

As for the price of fuel, the Department of Defense is experiencing the same major cost escalations that the private sectors of the economy are feeling. Overall price increases are 35 percent over FY 73 with the weighted average cost per barrel for all our products rising from $4.94 in FY 73 to $8.61 in FY 74 and is now estimated, as of 1 February 1974, at $11.12. When one considers that the DoD energy budget for FY 74 is 2.5 billion (Figure 8) and that a 29 percent increase is projected for FY 75, it is clear the impact of such large increases is truly staggering even in an $80 billion base.

DOD PARTICIPATION IN FEDERAL ENERGY PROGRAM

Last June President Nixon launched a federal program (Figure 9) to reduce energy consumption and shortly thereafter an Office of Energy Conservation was created in the Department of the Interior to coordinate all Federal and private efforts to meet the objectives set by the President. This program has as a goal a 7 percent saving across the board for all

PROJECTED JP - 5 SHORTAGES FOR JULY – DECEMBER 1973 (AS OF OCTOBER 1973)



% = PORTION OF JP-5 REQUIREMENT NOT COVERED

FIGURE 7

IMPACT OF RISING PRICES ON DOD ENERGY COST

$ IN MILLIONS

	FY 73	CURRENT EST. FY 74	EST. FY 75
PETROLEUM	1,381	2,027	2,706
NON-PETROLEUM	497	511	579
TOTAL	1,878	2,538	3,285
% INCREASE		35%	29%
WEIGHTED AVERAGE COST PER BARREL	4.94	8.61	11.12
% INCREASE IN AVERAGE COST PER BARREL		75%	29%

19 FEB 1974

FIGURE 8

FIGURE 9

"YOU ARE HEREBY DIRECTED TO REVIEW THE ACTIVITIES OF YOUR AGENCY AND YOUR CONTRACTORS WHICH PLACE DEMANDS ON OUR ENERGY RESOURCES AND DETERMINE HOW DEMAND CAN BE REDUCED."

PRESIDENT NIXON JUNE 29, 1973

"IN VIEW OF THE CRITICAL SHORTAGE OF PETROLEUM PRODUCTS TO MEET BOTH CIVILIAN AND MILITARY NEEDS, IT IS MY DESIRE THAT THE DEPARTMENT OF DEFENSE, BY EXAMPLE, DEMONSTRATE LEADERSHIP IN FUEL CONSERVATION."

OSD DIRECTIVE **MAY 19, 1973**

FIGURE 10

federal agencies. In the case of DoD petroleum fuels, this 7 percent saving is in addition to the 7 percent saving resulting from the Vietnam drawdown. Thus, the DoD petroleum usage should decrease by 14 percent. OSD (Figure 10) directed that this energy program be implemented with accurate feedback to measure our success. Currently DoD will aim to achieve a 15 percent overall energy reduction over FY 73 consumption as announced by OSD on 7 January 1974. The DoD conservation effort is particularly important from the Federal Government point of view since DoD consumes 85 percent of all the energy used by Federal agencies.

MAINTENANCE OF OPERATIONAL READINESS

The major challenge to the Department of Defense has been to effect this reduction without impairing the combat readiness of the various operational commands. Particularly in the case of aircraft, any reduction in the number of flying hours will have an effect on pilot proficiency unless some compensating action is taken. Many types of immediate action which can assist in saving fuel stocks are innovative in nature and can be instituted at the local level.

III. DOD'S RESPONSE TO THE ENERGY PROBLEM

I have been speaking to you of conservation measures since these are the most immediate steps the DoD can take. We have a fuel shortage today; we need an immediate response. In the long run, however, the DoD can attack the energy problem on many fronts.

In late September of last year, the Assistant Secretary of Defense (I&L) established the Defense Energy Task Group (DETG) to analyze the energy problem and to determine what action the DoD could take to minimize its effect on defense readiness. The DETG submitted its report to the Deputy Secretary of Defense on 15 November. The report contains 57 recommendations for DoD action to meet the energy problem. These are grouped in the seven areas below:

- Energy Requirements and Budget Impact
- Fuel Storage and Distribution
- Fuel Standardization
- Navy Petroleum Reserves
- Energy Conservation
- Energy R&D
- Organization for Energy Management

I am pleased to tell you that OSD has approved all the recommendations in our report. Therefore, the recommendations which I am about to summarize will form the basis for action by the Department of Defense.

ENERGY REQUIREMENTS AND BUDGET IMPACT

We need to know with increased precision how much fuel we need, how much we have, and where the shortfalls are in order to make best use of the energy we have. Energy data becomes especially important since it provides the basis for fuel allocation by the Federal Energy Office. As for our budgets, we expect our 1975 fiscal year energy costs to increase 75 percent over '73 levels due to price increases alone. The FY 75 budget has already been adjusted to reflect an increase in petroleum prices.

FUEL STORAGE AND DISTRIBUTION

I have mentioned our difficulty in procuring petroleum products. We believe that the Defense Supply Agency should acquire four petroleum facilities for use as central distribution points under 3 to 5 year leases in addition to the 36 we now have. These facilities would help to meet shortfalls in heating oil and in fuel for ground operations.

Ocean transportation presents us with a new problem in that the size of the average oil tanker is increasing. On the one hand, our strategic military POL terminals such as Rota, Sasebo, and Norfolk must be able to handle the larger tankers. On the other hand, we still need small tankers to get into the ports of whatever area may become a war zone. The Military Sealift Command is currently building nine handy-sized tankers of 25,000 DWT. A shipbuilding program is being considered for the '76 budget.

FUEL STANDARDIZATION

In the area of fuel standardization, we believe there are significant opportunities for decreasing the many types and grades of fuel. Indeed, in a time of fuel allocations, we may find ourselves with little choice other than to use a commercial-standard fuel or to do without. We are close to that point already with aviation gasoline, where the DoD is now almost the only user of AvGas 115/145.

We realize we may have to wait for a more appropriate time, but our second objective is to standardize on three vehicle fuels, one for aircraft, one for ships, and one for ground vehicles.

NAVAL PETROLEUM RESERVES

Figure 11 shows the fourth area for DoD action: The Naval Petroleum Reserves. Reserves number one and two are in Southern California; number three, Teapot Dome, is in Wyoming; and number four is in Alaska, completely undeveloped. As you know, the President has declared that reserve number one at Elk Hills would be made available to ease the present West Coast oil shortage, subject to Congressional approval.

NAVAL PETROLEUM AND OIL SHALE RESERVES

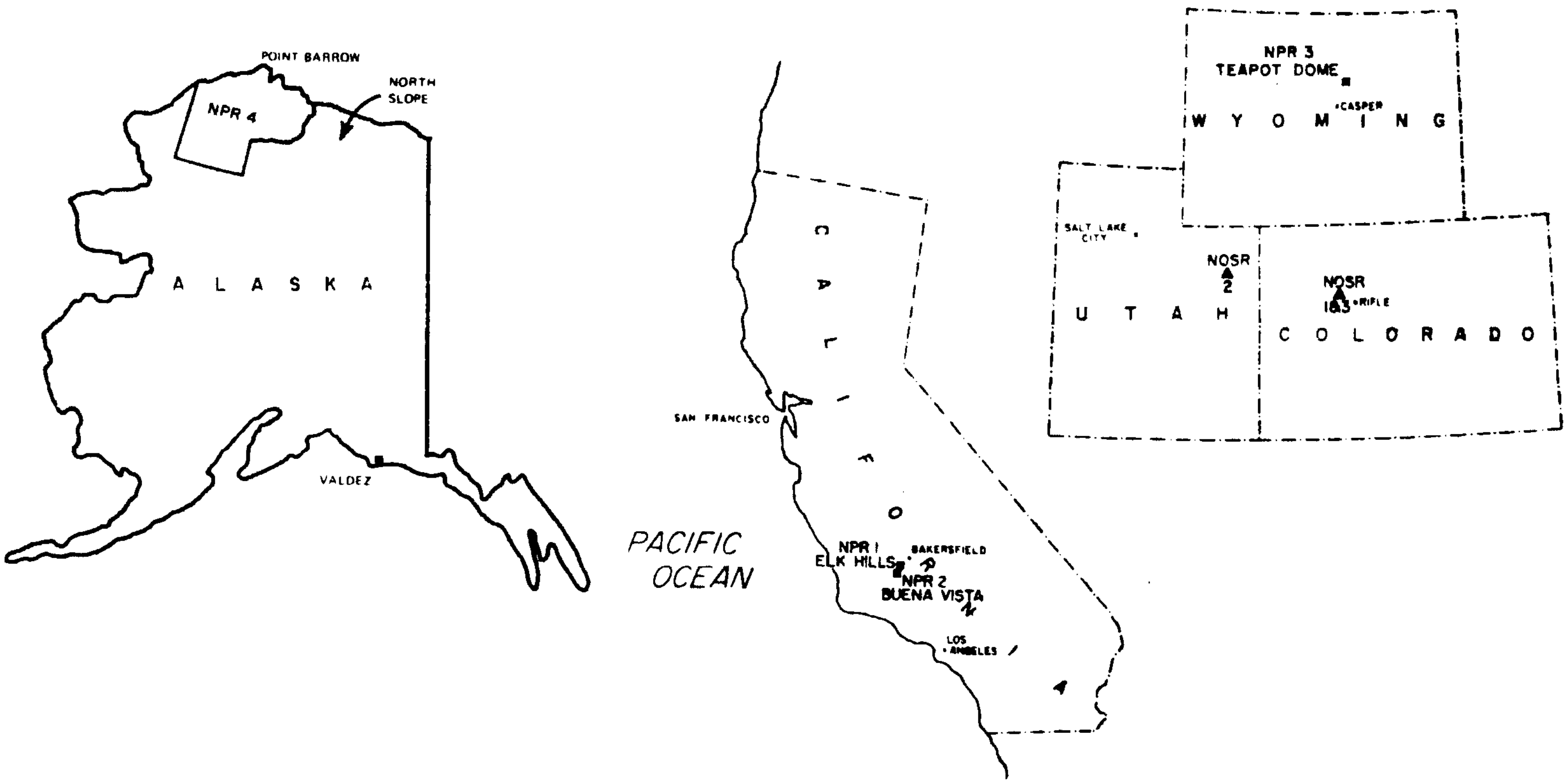


FIGURE 11

The existing producing capacity of these reserves is not large, however, and it will take time to develop them. For example, it will take five years to develop NPR #1 to its maximum production rate. As presently developed, none of the reserves can satisfy defense requirements during either peace or war. We have concluded therefore, that exploration and development of the full productive capacity of the Naval Petroleum Reserves is important to the national security of the United States.

ENERGY CONSERVATION

I have already shown you some of the immediate conservation measures we have implemented. These are some slightly longer-range moves which will be equally important.

- Earmark Military Construction Funds for conservation

- Require energy impact statements for Military Construction Projects greater than $300, 000

- Develop a method to quantify the impact of fuel shortages on readiness

In military construction, we found that energy-saving features often get squeezed out of a project because they add to its first cost, even though these features pay for themselves over time. Life-cycle costing should be the rule, at least as far as energy-saving features are concerned. We found that we already have the technology to make our buildings much more efficient than they are--often nothing more exotic is needed than proper insulation or an efficient air conditioning plant. Moreover, our people in the field know where these conservation opportunities are. But the money has not been available, even though many projects would pay for themselves in less than two years. Our funding doctrine must be changed to let these projects through.

ENERGY R&D

The DETG looked at reserach and development particularly closely. Skill at R&D is one of our national assets; the energy problem lends itself to an R&D approach; and the DoD is the largest purchaser of R&D in the country. We were, therefore, asked to establish guidelines for DoD support of R&D in the energy area. This we have done, as shown in Figures 12 and 13.

In assigning these roles, we were guided by two goals:

- First, the DoD needs new energy resources to meet its needs. It should participate with other government agencies and with industry or should offer incentives to developing new ways of supplying these energy resources.

- Secondly, the DoD needs to improve the efficiency with which it uses the energy it already has.

These two goals focus directly on the two essential elements of the energy problem: the supply of energy and the demand for it. These goals are consistent with the objectives of "Project Independence" announced by the President in his energy address of 7 November 1973.

ORGANIZATION FOR ENERGY MANAGEMENT

We are faced with a new management problem at DoD: the need to centralize diverse activities and to allocate a limited supply of energy within DoD. In response, the DoD made certain organizational changes, shown by the hatch marks in Figure 14.

- First, it established a Director for Energy. Broadly, his role is to be a program manager, coordinating all aspects of DoD programs for managing energy resources.

- Above him is a Policy Council and supporting him is an Energy Action Group.

- Supporting both of these organizations is a Defense Energy Information System which has been established under the Defense Supply Agency. It will provide the data which is absolutely essential if we are to manage our energy resources effectively.

FIGURE 12

RECOMMENDED
DOD ROLE IN ENERGY R&D *

R&D PROGRAMS	Time Frame For Application Near-Term (0-7 years)	Mid-Term (8-15 years)	Long-Term (> 15 years)
I. Improvements in Propulsion of Mobile Systems			
• Aircraft Engines	Lead	Lead	Participate
• Aircraft Engine Materials	Lead	Lead	Participate
• Ship Conventional Machinery	Participate	Participate	Participate
• Ship Nuclear Machinery (less reactors)	Lead	Lead	Lead
• Ship Superconducting Machinery	Lead	Participate	Monitor
• Land Vehicles— Diesel and Other Piston Engines	Participate	Participate	Monitor
• Land Vehicles— Turbine Engines	Participate	Participate	Monitor
• Land Vehicles— Transmissions	Participate	Participate	Monitor
II. Development of Alternative Fuel Systems			
• Synthetic Petroleum	Incentivize	Incentivize	Incentivize
• Direct Use of Coal	Monitor	Incentivize	Incentivize
• Hydrogen	Monitor	Monitor	Monitor
• Electrochemical	Monitor	Monitor	Monitor

*The primary justification for a specific program may be related to a military mission in which context the DoD role may differ with that shown in this matrix.

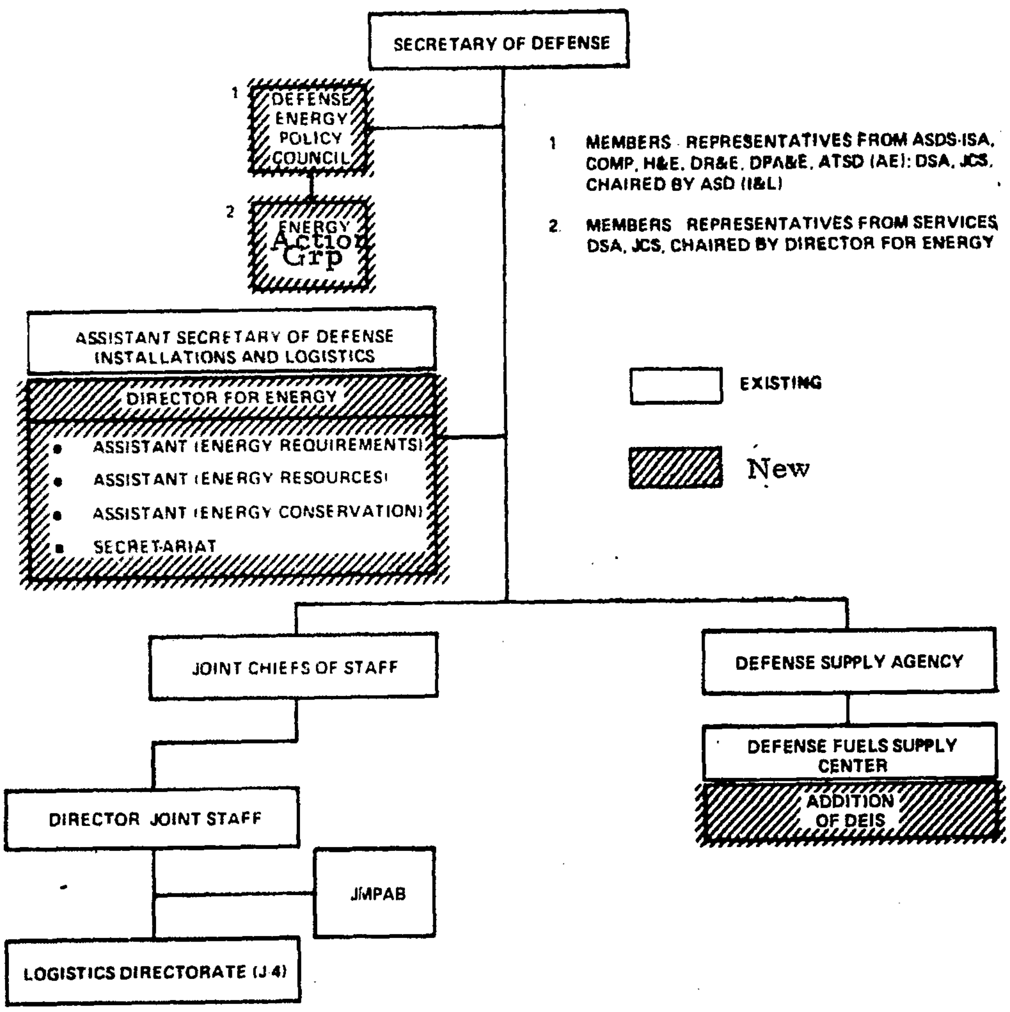
FIGURE 13

RECOMMENDED
DOD ROLE IN ENERGY R&D

R&D PROGRAMS	Near-Term (0-7 years)	Mid-term (8-15 years)	Long-term (15 years)
III. Reduction in Energy Consumption at Bases and Facilities			
• Improved Insulating Materials	Incentivize	Monitor	Monitor
• Heat Recovery Techniques	Monitor	Monitor	Monitor
• Advanced Methods of Energy Storage and Distribution	Participate	Monitor	Monitor
• Total Energy Systems	Participate	Monitor	Monitor
• Advanced Power Plants	Monitor	Monitor	Monitor
IV. Development of Advanced Energy Sources			
• Solar	Monitor	Monitor	Monitor
• Geothermal	Monitor	Monitor	Monitor
• NUC Fusion	Monitor	Monitor	Monitor

FIGURE 14

ORGANIZATION FOR ENERGY MANAGEMENT



Status of Defense Energy Task Group Recommendations

Based on the tenor of the reports from the various DoD organizations, it is clear that a high priority is being given to the DETG recommendations and that substantial progress is being made. Our overall assessment of accomplishments to date and the tasks remaining is as follows:

Organizational - Key recommendations have been implemented. Centralized organizations for energy matters are operational in OSD and the Services. Interdepartmental organizations have been established for policy approval, resolution of allocation matters and coordination of action on energy problems.

Informational - The Defense Energy Information System (DEIS) has been established and is operational. Effort is continuing to fully automate the system and to complete the master plan for DEIS to meet all internal as well as external energy information requirements. Subsequent experience has reinforced the urgent need for valid energy data available on a timely basis.

Logistical Facilities - Recommended studies and surveys are under way to re-examine logistical facility needs including prepositioned fuel stocks. This work will likely result in recommendations for additional tankage, tankers, prepositioned stocks and related equipment. A January 1, 1975 target date for definition of required facilities and the budgetary impact has been set.

Conservation - Conservation recommendations are being vigorously implemented throughout DoD. It appears that conservation goals can be met or exceeded, making DoD the acknowledged conservation leader in the Federal Government. The impact of fuel economies and/or shortages on operational readiness is a fundamental concern. Steps have been taken to provide continuous monitoring of change in readiness caused by the fuel situation.

Fuels Standardization - A continuing emphasis is being given to fuel standardization efforts. Each recommendation has been studied and some short term progress can be made. However, the worldwide energy situation is greatly limiting the availability of someproducts and changing historic price differentials. As a result, DoD's ability to standardize on designated fuels is greatly limited until adequate supplies become available.

Research and Development - The matrix for DoD participation in energy-related R&D programs has been expanded to further categorize activities and assign lead responsibilities. In the reviews now underway of specific proposals for DoD funding, consideration must be given to prospect of a greatly expanded energy R&D effort by the Federal Government and the private sector. The proposed 1975 Federal Budget will include $1.8 billion specifically for energy research and development - nearly doubling last year's budget.

Naval Petroleum Reserves - The "Engineering Plan for Assessment and Evaluation of the Naval Petroleum and Oil Shale Reserves" is in the process of updating and revision. The Supplemental Appropriation Act for 1974 provides $11.5 million for the first year's increment of exploration in NPR No. 1 and 4.

The overall status of the 57 recommendations is summarized in the following table:

	Number of Recommendations	Being Implemented	Modification or Delay Recommended
Organizational	5	5	0
Informational	8	7	1
Logistical Facilities	8	8	0
Conservation	20	20	0
Fuel Standardization	9	7	2
Research & Development	3	2	1
Naval Petroleum Reserves	4	3	1
Total	57	52	5

SUMMARY

In summary, we find this to be our situation. We presently face a fuel shortage, especially for jet fuel and middle distillates. As a result, we are taking steps to reduce consumption including such things as temporarily reducing operational training, and we, like you, may be without as much heat this winter as we would like. I have described some of the conservation strategies we have already adopted to save fuel. Because of these and because we are organizing ourselves for a long period of fuel shortages, I believe that we may be ahead of the civilian sector when it comes to energy conservation.

Our approach henceforth will be this:

- To conserve, by using only those resources which are needed, by avoiding wasteful practices, and by improving resource management.

- To requisition, under FEO allocation only those supplies which are absolutely essential for national defense; and

- To compensate, by seeking to use the Naval Petroleum Reserves to offset requisitions, and by directing energy-related R&D to assist in developing alternate energy sources and in improving the efficiency of energy consumption.

I wish to emphasize, however, that the U.S. Defense Readiness posture will be maintained. Of that, there is no question.

RECOMMENDED NATIONAL ENERGY RESEARCH AND DEVELOPMENT PROGRAM
FY 1975 to FY 1979

Self-Sufficiency Task	($ Millions) Short-Term Objectives	Mid-Term Objectives	Long-Term Objectives	Total
1. Conserve Energy and Energy Resources				
Federal	1,160	280		1,440
Private	3,200	300		3,500
Subtotal	4,360	580		4,940
2. Increase Domestic Production of Oil and Gas				
Federal	430	30		460
Private	4,300	200		4,500
Subtotal	4,730	230		4,960
3. Substitute Coal for Oil and Gas on a Massive Scale				
Federal	1,690	485		2,175
Private	2,500	500		3,000
Subtotal	4,190	985		5,175
4. Validate the Nuclear Option				
Federal	1,100	2,990		4,090
Private	1,000	250		1,250
Subtotal	2,100	3,240		5,340
5. Exploit Renewable Energy Sources to the Maximum Extent Feasible				
Federal	135	150	1,550	1,835
Private	220	30		250
Subtotal	355	180	1,550	2,085
TOTAL				
Federal	4,515	3,935	1,550	10,000
Private	11,220	1,280		12,500
GRAND TOTAL	15,735	5,215	1,550	22,500

Supporting Programs (incremental Federal funding to present programs)	
Environmental Effects	650
Basic Research	300
Manpower Development	50
	1,000

AMERICAN PETROLEUM INSTITUTE

by

Mr. Bobby Hall

I'm not sure that anyone can say today that they are highly qualified in energy. There are too many knowns and unknowns, and I'd like to discuss the way we see some of these unknowns.

Back when I was in industrial college, I was Chairman of the Energy Committee. At that time, there was indication of the forthcoming energy shortage. No one seemed to be excited about it. Today they are excited. What I'd like to do, since we have been talking about research and development, is give some background of the energy problem and bring in economics. The topic of this was supposed to be "The Need for New Petroleum Sources." That won't take long, I think, if you've waited in lines. I'd like to tie this together and show you petroleum's interrelationship with other fuels; what has happened to supply and demand and what will happen in the future; how we're going to have to counter these increased demands; and then, perhaps, sum up in about 19 minutes and 30 seconds, if you'll bear with me.

This first slide gives two circles showing primary energy sources in 1970 and 1985. There are three things that I want you to get from this slide: First, by 1985, oil is still going to be fulfilling 47% of our energy needs for fuel. It now provides 44%. The second thing that I'd like you to get out of this is the interrelationship of the fuels. As you can see, nuclear energy will be expanding to 13% of the total by 1985 versus less than 1% now. But things such as coal and nuclear energy are not the swing fuels that petroleum is. You can't put it in your car right now and drive; you can't use it in airplanes. Hydrogen fuels are some number of years away. At the same time, when unexpected demands occur and nuclear power plants don't come on the line as they should, or on time, environmental concerns demand that you shift from high sulfur coal or high sulfur oil; then petroleum products are expected to take up the slack. As you will see as we go along, that increases some demands that perhaps the industry was guilty of not foreseeing.

We are going to look at the sectors in which energy fuels are used, and the one in which petroleum is primarily the big fuel is transportation. Although transportation demands only 24% of the energy fuel, 50% of the petroleum products are used there. Within the transportation area itself, automobiles use about 53%, which means about 25% of total petroleum products are used by the automobile. So, when we start talking of conservation and increasing supplies, of course that's the first place that everyone hits – where we can conserve.

Basically, what happened to us was the classic example of domestic consumption and production not meeting. In other words, the demand exceeded the supply and you can see that that began at the end of the 1950's when we started talking about the plentiful foreign oil that cost two bits a barrel to produce. That was fine as it went, but other things increased demand – the world population growth. The thin red line on the right (on the slide) is the population growth since the discovery of Colonel Drake's well in 1859. More people, more demand; that's pretty self-evident. Also, there's a direct correlation between the standard of living and energy consumption. As the aspirations of the people over the world increase, and as these aspirations are satisfied, more energy is required. It's that simple. They are making their demands. Right now the United States has 6% of the world's population and uses one-third of the energy. This is something that the have-not nations are well aware of, as are the people in the Middle East. Put another way, last year, if everyone had enjoyed the standard of living that the United States enjoys, we would have a demand for energy that is equivalent to 600 billion barrels of oil. And the easy way to put it, when we do it with the kids of course, is to say that from 1970 to 1980, the world is going to consume more oil than they have ever since the first oil well was drilled.

This is a dark slide and you can scarcely see it but I'm not going to say much about conservation; you're well aware of this. But this is one graphic example. The one on the left portrays the average miles per gallon of a car in 1972, which is 12.4 miles per gallon. If we had had cars that gave us 20 miles per gallon, we'd have used one-third less gasoline or we could have saved 37 billion gallons. Projecting that to 1985, what this means is that, even with the increase in demand of the population and the increased standard of living, we would not be burning any more gasoline in 1985 than we are right now. So there is some room for conservation. Some of it is long term; you don't build 20-mile-per-gallon cars overnight, although Detroit is saying this.

As far as the petroleum itself, we need new sources. This slide is from a 1970 study done by National Petroleum Council (NPC) and the slide is broken down into four cases. The worst case is case 4 on the right-hand side and the reason it's the worst case is because the oil and gas imports would be at 38% of our total requirements. Well, as you know, we're about up to that point right now and this projection was for 1985. So the worst case – we're not even meeting that. Here is our reserve in natural gas; you can see it is continually declining. That means we are using more natural gas domestically than we are finding. That is not surprising. Natural gas is very cheap and clean – why wouldn't you burn it? The same is true in reserves of crude oil. Reserves have continually gone down. I'm not going to give you a long diatribe on profits and losses here although I'll mention them. This is what happened to our total exploration. As you see, we peaked out about 1957. Although we peaked there, the barrels of oil reserves discovered per foot drilled did not show any commensurate rise. Since then, it has fallen off and, when it falls off, of course there are several reasons, one of them being it is not profitable to drill.

I would like to look at return on investment (ROI) for a minute since you hear so much about it in the paper. All of those things show that in seven out of the last 10 years, the oil industry has been below the oil manufacturing average for return on investment (11.8% to 12.3%). That's a very small part and, indeed, last year was a good year for the petroleum industry and their profits were up. They were not the leading industry in being up in profits although they were among the top five. Our profit over the year was about 80%. The last quarter we were number two rather than number four but, when you start examining this great increase in profits, you want to remember such things as a base. You can throw out those figures and I'm not an economist, but you're well aware you must work with your base. For instance, I could say very well that the Washington Post had higher return on investment, increase in profits, than the petroleum industry last year. Simultaneously, they increased the cost of their product by 50% when they went up to 15 cents. I don't know anything about the Washington Post's product or what all that means. The figures are true but you can see where you can be fooled by figures. It would take another figure to look at it, but we all know that, if you are going to get oil, it's going to take money and it's going to take capital investment, and, therefore, you have got to have some return on your investment.

What has occurred is on this graph. This is an important graph. Again, it's the National Petroleum Council and they were predicting that in 1985 our demand would be up to about 28 million barrels per day for petroleum products. Our production would hover around 11 million barrels per day. Well, we're shooting well ahead of that, and we're going to be close to the Chase Manhattan estimate of 30 million barrels per day while at the same time, our production figures last year went below 10 million barrels per day. So the figure is really perhaps worse than we projected. Even if we had all the crude that we need, we are getting an increasing gap in refining capacity, and by 1985 we're going to have a gap there of about 7.7 million barrels per day. What this says is that something has to happen. We must get them from some place. We either have to conserve or get more supplies – or have to combine both, and that is probably what will occur.

There are several factors, and I won't go into all of them, but I would like to point out a few problems that have occurred which perhaps would not have been anticipated. This curve shows the loss of coal sales to petroleum products last year east of the Mississippi alone, perhaps for environmental reasons, perhaps for others. But what that says is that we burned 150 million barrels of petroleum products east of the Mississippi last year that ordinarily would have been replaced by coal, and the gentleman from the Coal Association will probably mention that in a few minutes. Let me show you one of the big users – it's sales of distillate to the public utilities plants. See how the demand has skyrocketed. Of course, the reason was a conversion from coal to maybe residual or residual mixed with distillate, and cutting down the high sulfur residual fuels with distillate. What this really means, if you want some figures, is that the public power utilities last year, for better or worse – I'm not condemning them; these are figures, I'm not pointing out any flaws – but they burned the equivalent of 125% of all the diesel fuel required for agricultural purposes, or 80% of all fuel required for the railroad, or 40% of the fuel required for trucks. But if you can replace that with coal or synthesized products, there's money in the bank. What this really says is that we have an imbalance in our current use of fossil fuels. We have enough coal to satisfy the nation's energy requirements for 400 years and yet our prime fuel source is petroleum. So there are some areas where we can certainly profit by trade-offs.

Where are we going to obtain the oil? Chase Manhattan Bank said that, in 1985, 50% of our oil was going to have to come from imports, and they say 30.2 million barrels. Out of that a large chunk is going to have to come from the Middle East. (Again, this was made before the Middle-Eastern situation; we're all aware of what the political situation is there.) This is another way of looking at it: In 1970, this was the movement and consumption of petroleum products in the world, and it looks as if we received about 400,000 barrels per day from the Middle East. This is what it will look like in 1980. As you can see, we are going to become more and more dependent on them because this is probably the most readily available area from which we can get the petroleum. We are going to get some from Alaska; the pipeline will be complete. We should be getting two million barrels per day, based on what we think is up there now. There may be a lot more up there; we certainly hope so. We have to get it and get it down and do something because I think the balance of payments is shown here. It would range anywhere from 35 billion to 70 billion dollars per year. This was when oil was a $4.10 a barrel. As you know, we are frozen at $5.25 per barrel for the major production in the United States now, but the world oil is up above $10.40. So you can see it's at least 70 billion dollars a year. We have to sell a lot of those F-4's and other things overseas to balance out that kind of money. My field is not international relations and I'm not exactly sure what the balance of payments means, but you can see that we have a problem.

One of the fallacies is that we are running out, or we have run out, of oil in the United States – domestic oil and gas. That's not true. We have more gas that hasn't been discovered than we have ever discovered in our reservoirs, and almost as much oil. The thing about that oil is that it is not where you stumble onto it by drilling wells at 3000 feet. Easy-to-drill wells are scarce anymore. Drilling must be deeper; drilling will be more costly. The people who wouldn't pump those wells below 10 barrels because it wasn't economical to use a pump because it wouldn't pay for itself, are now using pumps, if they can get them, and are putting pipes in the ground. So the supply is related to the price regardless of what you may hear from Capitol Hill on occasion. This is what we call the Fickle Finger of Fossil Fuels. Whatever it is, it shows that fossil fuels are here and we've got them for another few hundred years, and we can still use them – there's no doubt about it!

Some time in the future, we are going to have to do something different, and we have been hearing about this. What we're going to have to do is to plan ahead. Everybody says we don't plan ahead. We plan out to the year 2250 and you know good and well that plans will not be exact when you start going that far out, but they do give you some ideas.

First, wood, wind, water, and solar energy are not going to be with us for the next 15 years so, if you're figuring on running any businesses with these, I would suggest you live a long time so that your industry will be in good shape.

The second thing that this shows is that there are things on the drawing boards that are being discussed here that can help us. You can see that there is going to be increased use of solar energy but, before it really becomes important, it will be out of our lifetime.

You can also see that the fossil fuels are going to begin to peter out, with the exception of coal. Visualize coal's ever-expanding envelope as we go up in the odd years. An expanding envelope like that is the demise of the petroleum industry. About the only thing I can do is turn the discussion over to the gentleman from the Coal Association.

COAL RESEARCH AND DEVELOPMENT

by

Mr. Joseph P. Brennan
National Coal Association

I spend a great deal of my life these days trying to convince people that the coal industry is, in fact, not dominated by the oil industry. It is quite apparent – and this tangentially incident to the topic of my discussion, which is Coal Research and Development (R&D) – that the bituminous coal industry and, to a certain extent, the anthracite coal industry in the United States, has emerged into a period when, for the first time perhaps in this century, the growth potential of coal exists to a degree that we never really believed possible. It has also come to pass, for the first time in this century, that the success or failure of expansion of the coal industry is of much more importance than parochial interest within the coal industry itself. Because, whether or not coal can succeed in this very wonderful graph out to 2250, we are ourselves doomed at 2500 because we're not going to be around and you can sound very astute and really not say anything.

But the success or failure of the coal industry runs now to the basic economic, political, and military stability of the United States. Perhaps the best thing that ever happened to us is the Arab embargo because what it says is that America, self-sufficient, is infinitely better able to fulfill America's world role and infinitely better able to fulfill our domestic commitments than America dependent upon foreign resources. And you know the tragedy of this. Several months ago, the United States Navy ran a destroyer down the Delaware River using a fuel made from bituminous coal. Tragically, that fuel came from a pilot plant, not from a commercial coal refinery. Tragically, the economics of that fuel are very much in the ball park when we talk in terms of the prices we are now paying for foreign oil – prices that include a dependency that has many frightening ramifications.

However, my topic this afternoon is coal research. Coal research is a very important topic. It is something that we hear a great deal about today. It's a topic that has very good implications for the future of the industry for which I work, but it also has certain political ramifications that aren't quite so good.

I want to start talking about coal research essentially by saying that the research and development *is* vital to the future of coal. It's very obvious to us in coal that the technological base of coal extraction, distribution, conversion, and consumption must be sound and must be expansive if our energy needs are to be met. It's also tragically apparent that the technological base of coal extraction, distribution, and consumption is today inadequate in terms of the demands that are going to be placed on the industry. And, in order to set the parameters to discuss R&D, I want to tell you that the indications we have in the studies that we've made suggest that coal consumption by 1985 must be approximately 1.5 billion tons. Since the Arab embargo, the numbers have escalated somewhat to the range of 1.8 to 2.0 billion tons and, to put this in perspective, we are now producing about 600 million tons per year. This year, barring a strike, we'll produce about 650 to 660 million tons. The maximum production year in the history of coal in the United States was 630 million tons in 1947. So that what we are talking about is the doubling or the trebling of coal production. What we're talking about is adding two new coal industries on top of the existing one. And, therefore, in order to supply this type of tonnage, we're going to require an entirely new coal system – a system of which R&D is an important part – but nevertheless only *one* part.

Equally important over the long term, and perhaps more crucial in the short run, are governmental restraints which now inhibit coal development, and which interfere with the orderly expansion of bituminous coal. I am not attempting to denigrate the place of R&D in coal, because I've spent much of my life promoting it. I've spent much of my life suggesting before various private and governmental forums that coal resources represent 37 times the known reserves of petroleum in the Middle East – 37 times. And it's right here, and the people in West Virginia, Illinois, or Montana aren't going to cut it off. We must in fact begin development process and, as we do it, we must not become mesmerized by R&D by making it a panacea, but rather carry on R&D within the context, within the environment of a total coal delivery system, both governmental and private, which encourages expansion.

Looking then at the coal R&D program in the United States, it is quite obvious that R&D in coal has been sadly inadequate. For exampie, in 1968, I was appointed to the General Technical Advisory Committee of the Office of Coal Research (OCR). The OCR is the coal agency that is now the lead agency in developing gasification, liquefaction, and power generation technology. For FY 1968 and FY 1969, the OCR budget was 11 million dollars. This year, the OCR request, as it went from the President, was 300 million dollars. What has happened is that there has been a quantum jump in the midst of a crisis. Because of those earlier low-funding efforts, R&D programs in liquefaction processes, for example, have been deferred. Pilot plants have not been built, demonstration plants have not been constructed, and commercial technology has not become available. Liquefaction technology which would give us the ability to produce commercial fuel that can be used by the Navy, can help us shorten our gasoline lines and can give us, if nothing else, bargaining power in the discussions that Mr. Kissinger is now carrying on with our Middle-East friends. These plants were not built because of a lack of funds, because of a concept, because of a feeling that the United States of America could continually draw upon a cornucopia of unlimited resources – particularly energy – and could continue to make withdrawals from the energy bank, if you will, and never deposit. We're now painfully coming to realize that this is no longer true.

I think, as we look at the OCR program, as we look at the consumption program, and as we look at the needs for R&D, we have to face the fact that the problems relating to energy inadequacy on the supply side are compounded and made difficult by problems relating to the inadequacies on the supply side in mining. It has developed that we have come to a place where we have the demand of 1.5 or 1.9 billion tons. In fact, we do not *have* the mining technology and, in fact, we have a concurrent problem of meeting a demand level that is growing beyond anything that we have ever dreamed of in the last 10 years, with the supply technology and the extraction technology of the 1950's. It would be as if we hadn't built a new weapon system and we had stopped with the B-36 aircraft in 1950. That's what happened in coal. I think that the result of this past apathy is quite evident, that the result is now an inadequate, obsolete coal industry. I don't want to leave on a note of problems because I think the problems are really opportunities and, as I view the next 20 years, we can at least develop the options of sufficiency. We can at least continue our economic and social progress; we can, in fact, provide the industrial base which will permit us to carry out our defense commitments if – and I think this is crucial – we are prepared to make the national commitments to do so.

In line with that, I would like to suggest to you certain areas in the coal research programs that are absolutely essential and certain areas where you are now seeing additional funding made. However, before I go into the specific areas I would like to discuss for a moment the governmental framework – for the bulk of coal R&D is government R&D. There is an increasing amount coming from private industry but, at least for the present, the bulk is government. Unfortunately, the research structure in government is severely fragmented and what has happened is that the growth of interest for R&D has simply surpassed the governmental ability to use the funds in such a way that they can maximize and optimize R&D results. So we have a great debate nationally and where I think the debate is leading is the establishment of a central energy R&D agency – an R&D agency that can translate some priorities into research problems that will give us the technology and the hardware that we need. I'm not sure what you're going to call the agency, but I do know we need it.

Let us move on to the areas of research. If you could pick one area to the exclusion of all others, I would very strongly suggest that our efforts must be made in the area of mining. I say that for two reasons. First, the underground mining sector counts for about 50% of our total production and I think this percentage will continue for the next 10 years. Unfortunately, this productivity has been in a period of national decline. At the present time, the only R&D that is being done is in the area of coal mine health and safety, which is extremely desirable but which is only a part of the job. There is a budget request this year for about 50 million dollars for mining technology, and what we are talking about is replacing our present mining system or improving it to the point where we can begin to get maximization of underground mining systems. Let me give you an example: 50% of the underground mining in the United States is done by the so-called continuous miner. and the continuous miner is a machine that, in one process, cuts and loads coal. The continuous mining machine is probably one of the greatest misnomers in American history because, in fact. it mines coal, the purpose for which it exists, 30% of the time. It moves coal away from the face by a batch process by loading it on something we call a shuttle car – a shuttle car which is a little kiddie car that holds two or three tons of coal. Therefore, the rate of mining is determined by the rate at which you can get the coal away from the face, the rate at which you can move coal, and the rate at which you can drain the methane away in advance. So what we are talking about is a machine that is not doing anything productive 70% of the time that the machine is in a coal mine. Quite obviously, that is inadequate. In light of this, the National Coal Association and others have been suggesting a major R&D program in underground mining technology. Some aims of the program are: (1) to make that continuous miner more efficient, (2) to develop automated systems that will be needed in mining, (3) to shorten the time of development of coal mines (which is now 3 to 5 years), and (4) to do something that will permit coal mines to operate continuously and efficiently.

The second major area of interest of the coal mining industry research program is in liquefaction. This is an area that has been sadly neglected in the coal research area for many years and we look upon liquefaction as needed for two major reasons: First of all, it provides an alternative to imported fuels, especially for boiler fuel purposes. You saw that lovely chart, which has caused more than one heart attack in the coal industry, of the use of oil by electric utilities. This is primarily due to environmental reasons and is one of the primary causes for some of those long gasoline lines we've been enduring. In fact, this summer, one of the critical shortages of petroleum products will be residual products which are used for boiler fuel purposes. Coal is a perfect substitute there. Secondly, for the longer term, I think that coal liquefaction, in conjunction with oil shale development, offers the United States an alternative to Middle East oil dependency. Now, the problems connected with liquefaction and the problems connected with creating this alternative are not all R&D related. South Africa is making beautiful gasoline from coal. The problems, in many cases, are political and economic. And I would suggest that you, I hope, are going to see a commitment made by the United States Government, in one way or another, to underwrite the development of liquefaction. What we are talking about is a 4 million dollar investment, amortized over 20 years, that will produce a product that will sell at 7, 8, or 9 dollars a barrel, when the Arabs can produce it at 25 cents a barrel anytime they want to. There is pilot plant work going on in liquefaction, and I think that this is going to lead to early demonstration plants and the construction of commercial facilities. Exxon, for example, the other day announced a 400 million dollar program. There is a great deal of interest in this liquefaction through the world. Last October, the National Coal Association, in conjunction with the Departments of State and Interior, held an international coal research conference with the nations of Western Europe (including France, by the way) and Canada. And a tremendous amount of interest in using coal liquefaction as an alternative to Middle-East oil is shown. It's expensive.

A third major area is gasification. In the coal research program, I guess this area is more advanced than any other. We have at least four, five, or six (depending on the stage) gasification programs announced. And yet you know the tragedy, all are using Lurgi technology developed by the Germans in the late 1930's. That's our "advanced state" in our ability to use coal.

The fourth major area, which is probably a pet of mine because I've been involved with it for many years, is improving the power systems. You know today, when you go throughout this country or when you testify on "The Hill" as I did this morning, you hear words like, "We must somehow reduce the slope of that demand curve . . . We must conserve energy." And that's a good idea. We *must*, in fact, conserve energy. And yet, every time I take a ton of coal, every time I take a hundred Btu's of coal, or a hundred Btu's of gas, and put it under a utility boiler, I get 40% of that as usable energy – which means I waste 60%. Now, conservation means to me certainly using less energy where you can, but it also means eliminating waste. And, unfortunately, because of the technology, waste in the power industry is an everyday occurrence. It is something that we could have tolerated in our era of self-sufficiency and abundance, but no longer.

Finally, the R&D program in coal mining must involve the activities in the pollution abatement area, and this is especially true of sulfides and sulfates. You must include nitrogen oxides and those problems dealing with water pollution. However, while we very definitely need research and development (and especially development) we have to test those systems that are now in the pilot plant state. We have to bring them to commercial feasibility. A large part of the problem again runs to our ability to use existing fuel sources in existing power plants and, instead of putting scrubbers on, or instead of waiting until we have developed the technology, use control strategy, an approach that will give us properly controlled ambient-air conditions. I think that where we are as a nation in this regard is at a point where we must take a look at our entire pollution-abatement program. I spent a lot of years, as the Chairman said, working for the United Mine Workers, and I have a very narrow outlook on pollution abatement and environmental control. We need them. Every social good has a cost, every economic good has a cost, and environmental costs are part of it. However, environmental controls and environmental regulations were designed in a period when we had energy in abundance. I can remember, for example, testifying before Congressional committees and meeting with environmental and other groups when regulations were drafted on 0.7% sulfur coal, very little of which exists east of the Mississippi River, at least in commercially available quantities. The answer is very simple: look at all the beautiful Western lignite and sub-bituminous which we are precluded from using because we are going to have to strip it. All I'm saying is that, "Yes, we must." There's a lot of money being spent on this, and there will be a tremendous amount more, and it's something that we must do. Along the way we are going to have to make the very hard decisions as to what we can do and what we cannot do, and as to the cost associated with the nondevelopment of the resource and the cost connected with the development of the resource.

In short, and in conclusion, what I am essentially saying is this: The coal R&D effort has now jumped from 11 million dollars in 1969 to somewhere about 400 million dollars this year. The coal research effort, which you hear much about in terms of making America self-sufficient in energy, is part of an overdue reaction on the part of the government, on the part of the American people, and on the part of energy consumers. The importance of coal – and my training is in economics – lies in one very simple fact: it is here, and it is abundant. Developing it and using it are going to involve a tremendous recognition and a tremendous affirmative action on the part of everybody – on the part of the coal industry certainly, on the part of the government certainly, and on the part of the consumers certainly.

An important part of that affirmative action is research and development. With R&D, we can use coal in an environmentally acceptable manner at reasonable cost levels. Three trillion tons, or one and one-half trillion tons, or three hundred billion tons of coal – pick your own source and pick your own number – can become for at least the rest of this century and the first part of the next century the energy basis for a self-sufficient America – the basis that will enable the American nation to pursue its domestic and foreign goals free from the type of overt blackmail that we are now facing.

Thank you very much.

SESSION II

ENERGY SOURCES – PART I

Chairman: Dr. William Magee
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AEC

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

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at the

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THERMONUCLEAR FUSION ENERGY

Fusion—the combining at high temperature of light elements to make heavier elements—has often been called the ultimate solution to the problem of energy supply. There are several reasons:

- Deuterium, the basic fuel, is universally obtainable from water, is virtually inexhaustible, and is obtained at a negligible cost. The energy content of 1 gram of deuterium is equivalent to the energy content of 2500 gallons of gasoline.
- The "combustion product"—helium—is non-toxic, non-noxious, non-radioactive. It is a valuable product.
- There would be no chance of a runaway nuclear reaction.
- There would be relatively low radioactivity associated with the plant (that associated with the fuel if tritium is used and that induced in the structural materials).
- There is the possibility of high thermal efficiency and consequently a potential for reduced thermal pollution.
- Fusion could supply a large fraction of the total national power demand, independent of geógraphical location.

These are impressive potential advantages, well-worth pursuing vigorously. The question in everyone's mind is: "How probable is it that these advantages can be realized in practical power systems, and when?"

Fusion occurs most easily between the heavy isotopes of hydrogen (deuterium and tritium) at very high (stellar) temperatures. The basic processes are summarized below:

Fusion Reaction	Ignition Temperature (° Kelvin)	Energy Released per Reaction (MEV)
$D + T \rightarrow He^4 + n$	50,000,000 (5 keV)	17.6
$D + D \nearrow He^3 + n$	500,000,000 (50 keV)	3.3
$\searrow T + p$		4.0

Deuterium-tritium reactions are self-sustaining above temperatures of 5 keV. The corresponding temperature for deuterium-deuterium is 50 keV. If even higher temperatures are achieved (100 keV), fusion between hydrogen and helium isotopes also becomes possible:

$$D + He^3 \rightarrow He^4 + P + 18.3 \text{ meV}$$

At the temperatures involved in any of these reactions, the fuel gas is fully ionized, i.e., the fuel consists of an assemblage of hydrogen nuclei and electrons called "plasma."

Not only must this plasma be ignited, but it must burn for a time sufficient to repay the energy invested, with energy to spare for practical use. The burning time required depends inversely on the density of the ignited fuel—a very high power density requires only a short burning time and vice-versa. This results in a variety of so-called "approaches" to fusion power as summarized below:

Approach	Popular Name	Typical Density (cm^{-3})	Typical Burning Time (sec.)
Open Systems	Magnetic Mirror	10^{13}	10
Low Density Closed Systems	Tokamak	10^{14}	1
High Density Closed Systems	Theta Pinch	10^{16}	0.01
Laser Pellet Systems	Laser-Fusion	10^{24}	10^{-9}

Vigorous research and development programs are in progress world-wide aimed at understanding the physics of these approaches sufficiently to design with confidence devices capable of reaching the above conditions.

Fusion research for power production began about twenty years ago, in 1952, at a very low level. With hindsight, the devices which were built then seem pitifully inadequate, although the expectations for them at the time were very large. The first ten years of fusion research can be described as a painful learning experience: learning from failure by explaining the failures with new physical models; moving forward to new experiments, only to fail again. In the process, however, the basics of a new science, plasma physics, materialized.

During the 1960's, things improved, the science became very sophisticated, and experimental verification of the key predictions of theory was obtained in devices of increasing size. There were two key achievements:

- fusion temperatures of tens of millions of degrees were achieved at fusion reactor densities of 10^{14}-10^{16} deuterons/cm^3 in the early 1960's.
- gross plasma losses were suppressed by use of theoretically-predicted "magnetic-well principles" in the mid-1960's.

These achievements were crowned in 1969-1971 by the discovery (first in the Soviet Union) that a doughnut-shaped magnetic bottle called the "tokamak" had very favorable plasma confinement properties. Since that time, world attention has begun to focus dramatically on tokamaks as possibly providing a route through the physics/technological maze to practical fusion power systems.

Projections were made that the achievement of reactor-like conditions (temperature, density and confinement time) in hydrogen plasmas could be expected by the 1980-82 time period. This goal was often referred to as the "demonstration of scientific feasibility." Commercial fusion power development was projected to take an additional 20 years—culminating in a demonstration power plant around the year 2000.

During the past two years, world progress in fusion research has been proceeding at a rapid pace. So much so, that in July 1973 a reassessment of the status, objectives and projections for the U.S. fusion program was initiated.

The recent past has been marked by an unprecedented increase in the number of cases where experimental devices have operated successfully in accordance with theory and in which significant achievements have been demonstrated.

In the fall of 1972, the Adiabatic Toroidal Compressor (ATC) experiment at the Princeton Plasma Physics Laboratory (PPPL) successfully demonstrated compressional heating of a tokamak plasma and, for the first time, the plasma density regime of interest for a fusion reactor was reached in a tokamak plasma. This technique would be capable of bringing tokamak plasmas to ignition temperatures in a larger facility.

In February 1973, the Oak Ridge Tokamak (ORMAK) at Oak Ridge National Laboratory (ORNL) successfully demonstrated tokamak operation in a device scaled-up in size.

In April 1973, again in ATC, the heating of ions in a tokamak by the technique of injecting neutral beams into the plasma was demonstrated for the first time. The ion temperature increase was modest (20%) but the principle was proven. Higher power heating experiments were recently performed in ATC and have raised this increase to 35%. Still higher power experiments are currently in progress in ORMAK.

In the spring of 1973 at General Atomic, the Doublet II experiment demonstrated gross stability of a plasma with noncircular cross-section. This is an important result since theory predicts that the cost of tokamak reactors with non-circular cross-section will be less than for those with circular cross-sections. Modifications of the Doublet II are underway aimed at optimizing this result.

In the High Density Systems area, the Scyllac experiment at the Los Alamos Scientific Laboratory (LASL) demonstrated gross stability in the first toroidal sector (1/3 of the torus). Completion of the full torus has recently been completed and, based upon the success of the Scyllac Sector experiment, optimism is high that toroidal equilibrium and stability will be demonstrated before the end of calendar 1974. This would be a major milestone achievement on the road to a high density, theta pinch reactor.

In the Open Systems area there have been major successes in two mirror experiments. During FY 1973, the 2X-II experiment at the Lawrence Livermore Laboratory (LLL) demonstrated improved plasma confinement in agreement with a recently developed theory. The theory indicates the means to achieve the plasma conditions necessary for reactor operation of a mirror device and modifications of the 2X-II are underway aimed at the objective of permitting a meaningful test of this theory by December, 1974.

In July 1973, the Laser-Initiated Target Experiment (LITE) at the United Aircraft Research Laboratory (UARL) successfully demonstrated that a laser-target plasma could create the type of plasma target required for plasma buildup by neutral beam injection in mirror devices. This technique could provide the basis for starting up a steady state magnetic mirror fusion reactor. Modifications of the LITE experiment are underway aimed at neutral injection experiments in 1974.

In laser-fusion, several hundred joule lasers came into operation alongside facilities to irradiate pellets. This suggests that 1974 may be a critical year in the evaluation of laser-fusion physics.

New Directions

This chain of successes shows the accelerating progress of the magnetic confinement systems program in all three major areas of research. This and the outlook for major advances in the near-term led to a major re-examination of the whole fusion power program and resulted in the following general conclusions:

- Recent experimental successes, in particular in toroidal tokamak plasmas, have moved prospects for successful confinement forward faster than had been anticipated only one or two years ago.

- The outlook for further significant gains in plasma confinement and heating now seems excellent over the next few years.

- Consequently, the program is beginning to seriously plan for deuterium-tritium (DT) burning experiments at a time earlier than previously anticipated.

- Simultaneously, appropriate new hydrogen experiments are being planned to answer those physics and engineering questions, which are more simply and economically examined in non-burning plasmas.

Tokamaks presently do and will continue to receive primary emphasis in the U.S. CTR program. They are currently considered the most promising approach for successful confinement. Future directions will include: demonstration of confinement at reactor-like conditions; the exploration of alternative toroidal configurations that offer the possibility of more economical systems; and the testing of engineering features such as divertors (an impurity control device) and fueling systems. Design of DT burning plasma systems will proceed aiming toward early implementation.

The theta pinch approach has demonstrated successful heating and confinement of thermonuclear plasma in linear systems. It is now being pursued on a larger scale (Scyllac) to resolve the problems of high-beta (ratio of plasma pressure to magnetic field pressure) confinement in toroidal geometry. Plans are being made to combine the heating and confinement elements in a future DT burning plasma experiment, which will include technological features appropriate to a pulsed reactor system. One advantage of the theta pinch approach is that its experimental beta is already adequate for a reactor.

The open geometry of mirror systems offers a potential reactor engineering advantage such as natural divertor action. The additional advantage of small size suggests consideration of open mirror systems as an economic near-term approach to an externally-driven DT burning plasma experiment, which could be used to perform some of the engineering research functions, such as materials testing, required for the overall program. Such a step would also allow further exploration of mirror systems as fusion reactors.

As a result of these and other recent events it is concluded that the program is in a position to proceed with large DT fueled Fusion Test Reactors an an earlier time then previously projected and that, if adequate funding is provided, the date of initial operation of the first fusion power demonstration plant can be advanced by several years. The present schedule compared to the previous schedule is shown below.

Milestones	Dates for Successful Operation: Previous Plan	Dates for Successful Operation: Current Plan
Reactor plasma conditions in hydrogen	1980-82	1977-79
Fusion Test Reactors	1984-87	1979-82
Experimental Power Reactor	1991-93	1983-87
Demonstration Power Plant	2000	1995-98

It is anticipated that tokamaks, theta pinch systems, magnetic mirror systems, and laser-fusion systems will all play an important role in the overall development of fusion power systems for the nation. However, in order to increase the chances of achieving an early proof of the practicality of fusion power systems, the tokamak, which is considered to be the most promising approach, has been assigned top priority. This U.S. stance is consistent with the other major world efforts in the U.S.S.R., Europe, and Japan.

The fusion program is now becoming oriented toward the eventual development of a demonstration power plant, whereas previously it was strictly research-oriented, i.e., aimed at the demonstration of scientific feasibility. This means that it must begin now to plan for, and to begin to perform, engineering-oriented tasks so that key engineering problems can be identified and development programs begun aimed at their solution on a planned time scale. The key engineering areas for fusion power plants as now seen, are:

- Superconducting Magnets: The magnets envisioned for the near and long term will be considerably larger than anything yet constructed. Design and fabrication of prototype magnets will begin soon, aimed at applications in the first fusion test reactor.

- Heating Technology: Higher power sources, both neutral beam and radio-frequency, must be developed to heat the larger volumes of plasmas which will be present in future devices and reactors.

- Materials Technology: A critical problem for fusion power systems is the effects of 14 meV neutrons on the lifetime of materials used in construction. No significant body of knowledge exists on this subject. A considerable expansion of activity in this area is projected.

- Systems Studies: Various kinds of systems studies will be initiated to guide the development of all major aspects of the fusion power program. These will include parametric systems analysis, fusion reactor design studies, new systems concepts and cost-benefit studies.

An important consideration in the fusion engineering program, as it develops, is the establishment of an industrial capability for the components and systems required.

Outlook

Fusion power R&D is at a critical point. Research questions bearing on the scientific feasibility of the concept are being answered and the results indicate that the critical questions for practical fusion power will be engineering and economic rather than physics. To pursue these questions, test reactors must be constructed and a major effort must be devoted to the systems analysis and engineering developments required. With adequate funding, the goal of operating a demonstration fusion power reactor before the end of the century appears to be a reasonable one.

PICTORIAL OVERVIEW OF THE HYDROGEN-ENERGY CONCEPT

by

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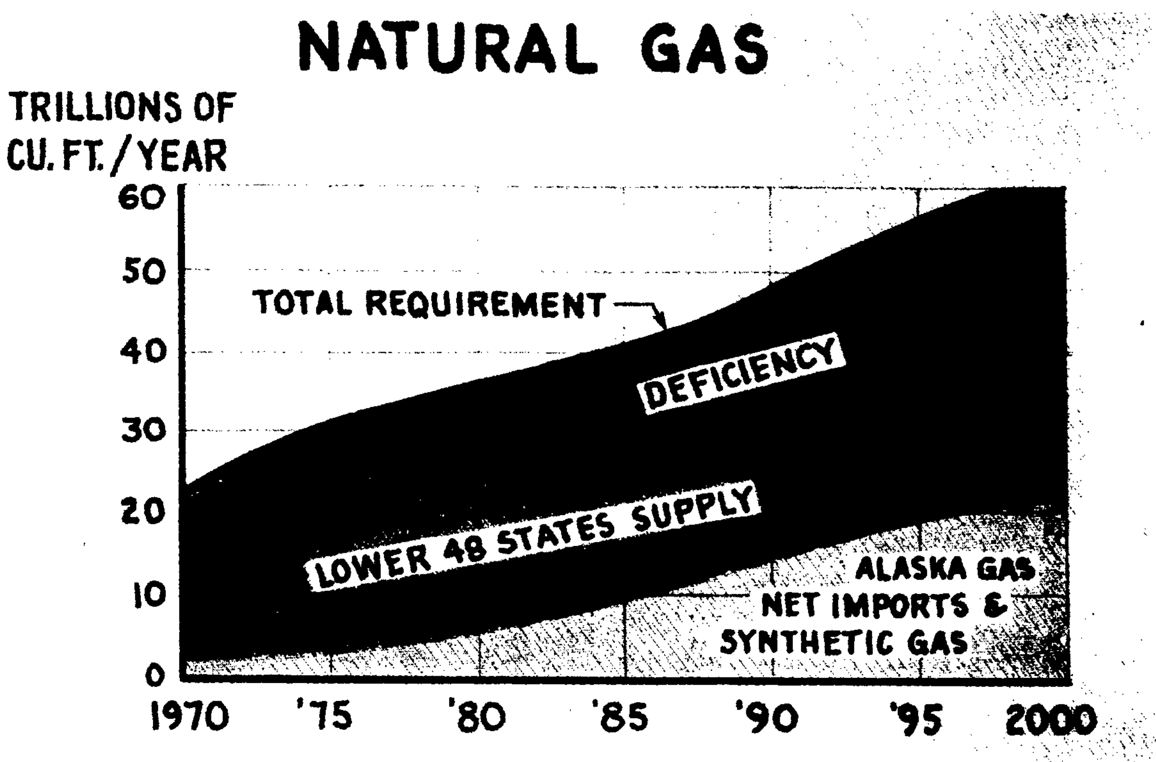
INTRODUCTION

Hydrogen alone, and Hydrogen/Oxygen bireactant, produced through water-splitting reactions by means of non-fossil primary energy sources (nuclear, geothermal, solar) provides a most promising avenue for supporting the World's future energy requirements beyond our present fossil-fuel era.

This "Hydrogen Economy" concept is already under serious study in all of its ramifications in the United States and abroad. A large number of reports, technical papers, and articles in the press have appeared reflecting these efforts. In a number of instances, hydrogen-oriented experiments and demonstrations have been carried out with impressive results. The pace of these investigations is clearly intensifying in response to today's energy and environmental problems.

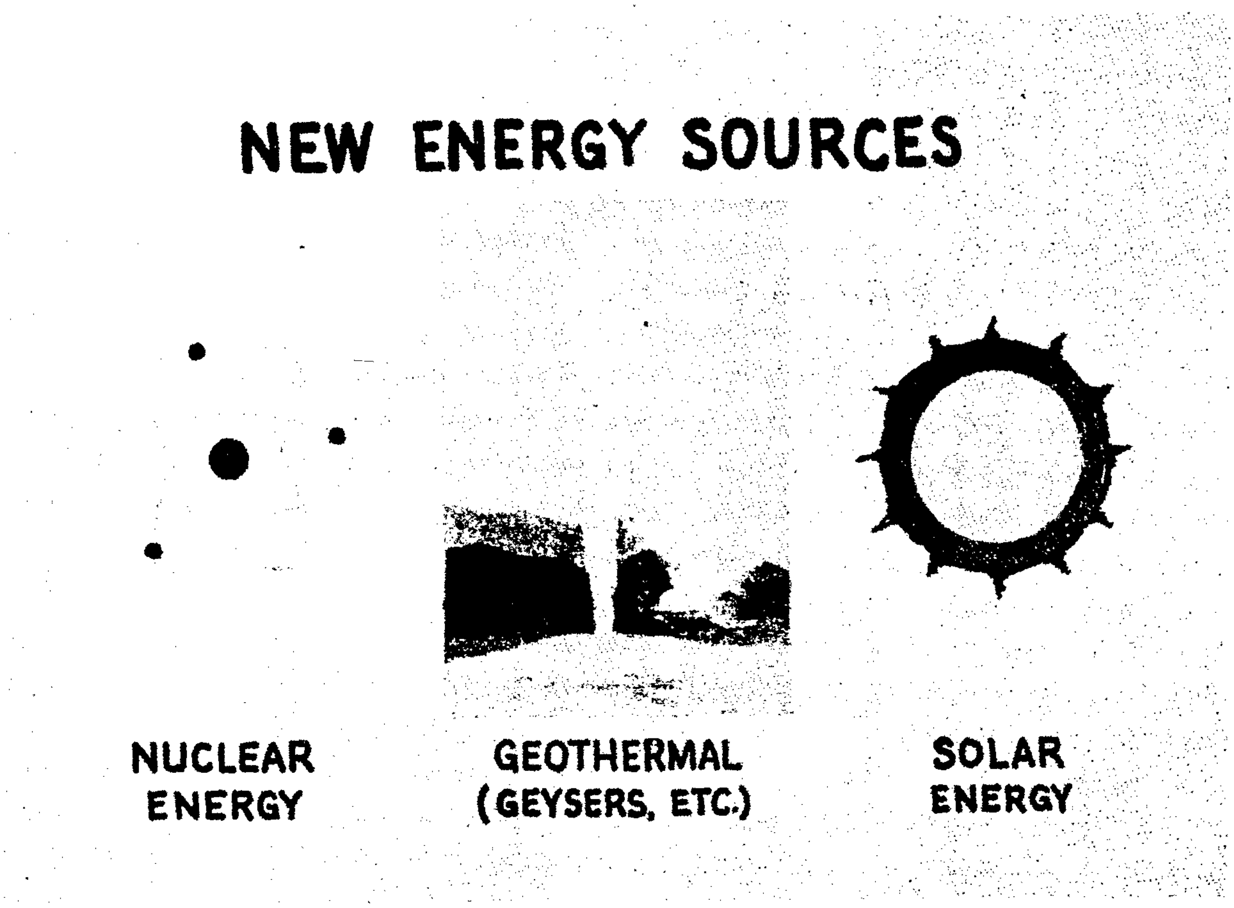
ENERGY PATTERNS ARE CHANGING

With our limited domestic resources of gas and oil, and a rapidly growing demand for energy, the United States and the rest of the World will undergo substantial changes in energy supply patterns. In the United States, there is already a widening deficiency between the supply of natural gas and the growing demand for it.



NON-FOSSIL ENERGY SOURCES WILL BE MANDATORY

New, relatively "inexhaustible" energy sources such as nuclear, geothermal, and solar energy will have to be developed as we pass from the present fossil-fuel era to a non-fossil energy dependency in the century ahead. Illustrating this trend, nuclear electric generating plants are targeted to produce half the nation's electricity by the year 2000.



'HYGAS' COAL GASIFICATION PILOT PLANT

In anticipation of these evolutionary changes, the Nation's Energy Industry and related Governmental organizations are carrying out far-reaching research and development programs. Today's progress by the industry/government team in the very important area of coal-gasification for supplementing natural gas exemplifies our ability to pioneer needed technical advances.

Photograph Courtesy - Institute of Gas Technology

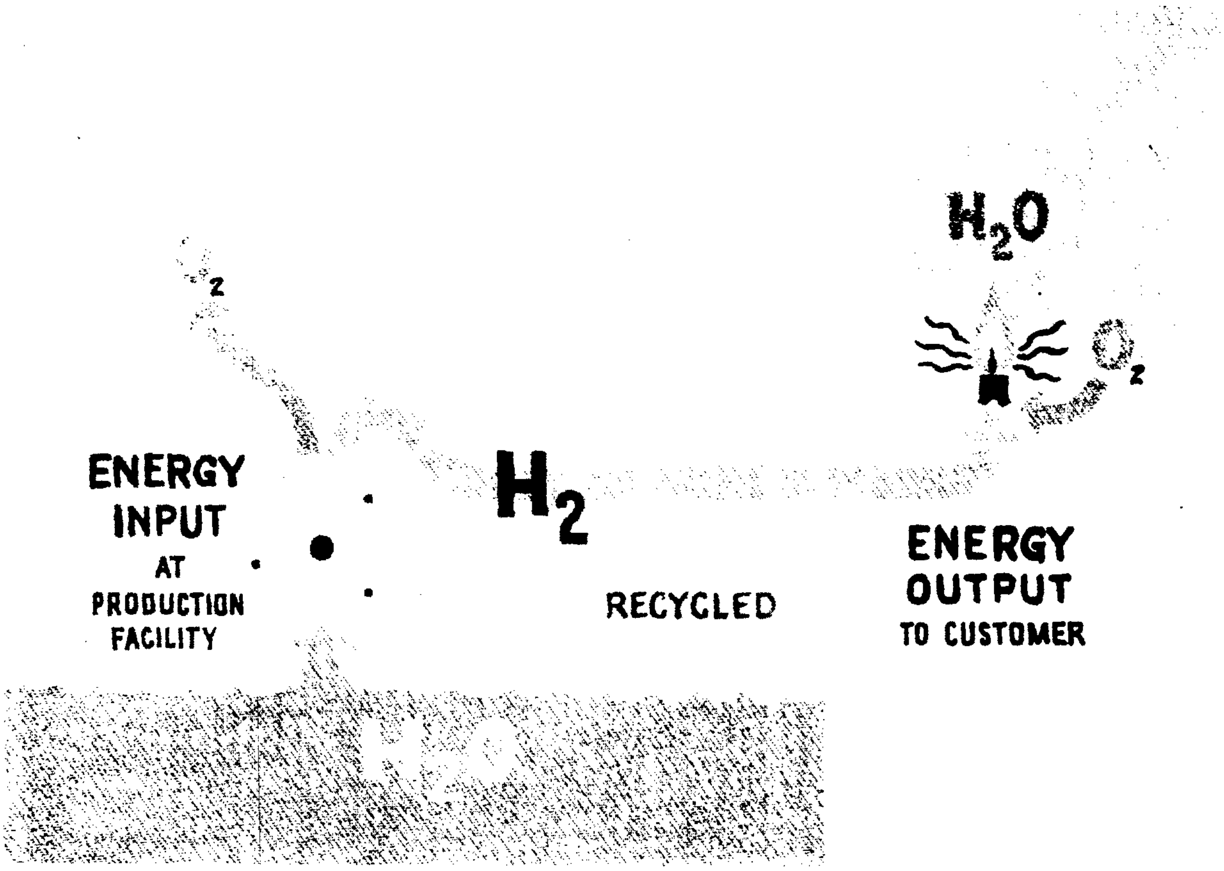
A NEW ENERGY DELIVERY CONCEPT

Of special interest to our long-range future is a new energy-delivery system based on Hydrogen now being assessed by the natural gas and electricity industries and others around the World. Such a system can, in principle, continue to serve energy customers well beyond our present self-limited fossil fuel era.

HYDROGEN ENERGY SYSTEM

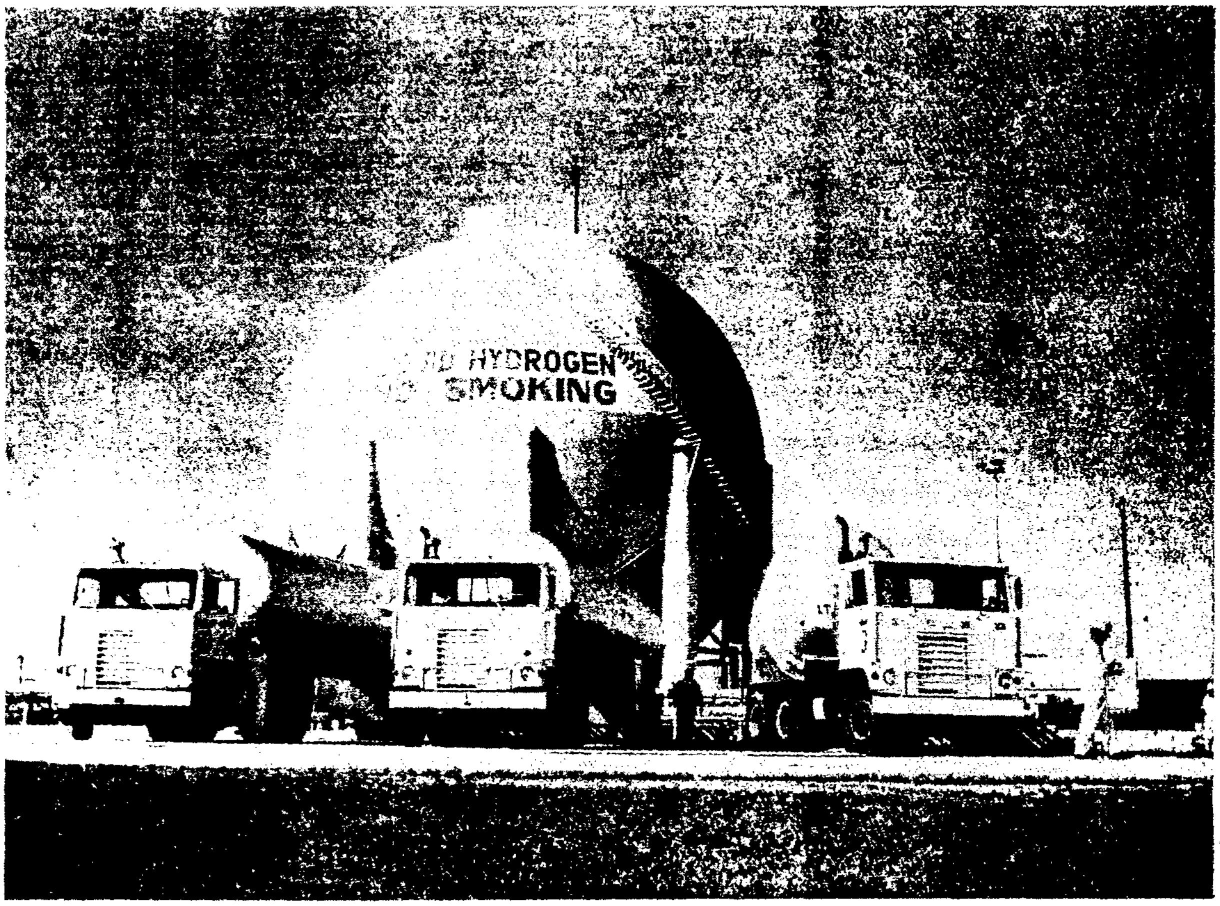
HYDROGEN-ENERGY CYCLE

Hydrogen, produced from water either by electrolysis (a well developed technology) or by direct use of heat from nuclear or solar sources, can be used to conduct this energy to the user. When consumed, Hydrogen produces only water as combustion product. It is thereby the cleanest possible fuel.



LARGE CRYOHYDROGEN TANK

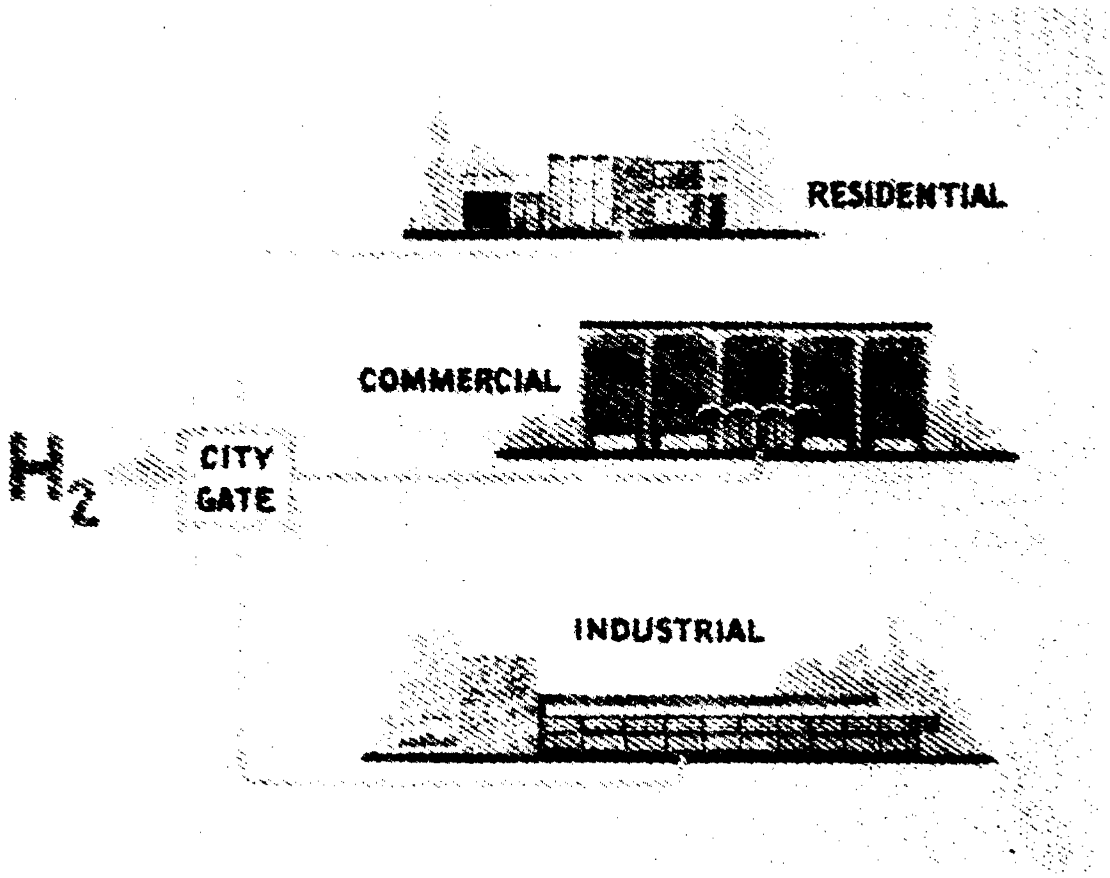
Like today's natural gas, Hydrogen can be economically transmitted over long distances in unobtrusive pipeline systems underground. It can also be conveniently stored underground in depleted gas and oil fields and aquifers. In analogy to LNG (liquefied natural gas), Hydrogen can be liquefied at very low temperatures to provide flexibility in its transportation and storage.



Photograph Courtesy - National Aeronautics and Space Administration
Kennedy Space Center, Florida

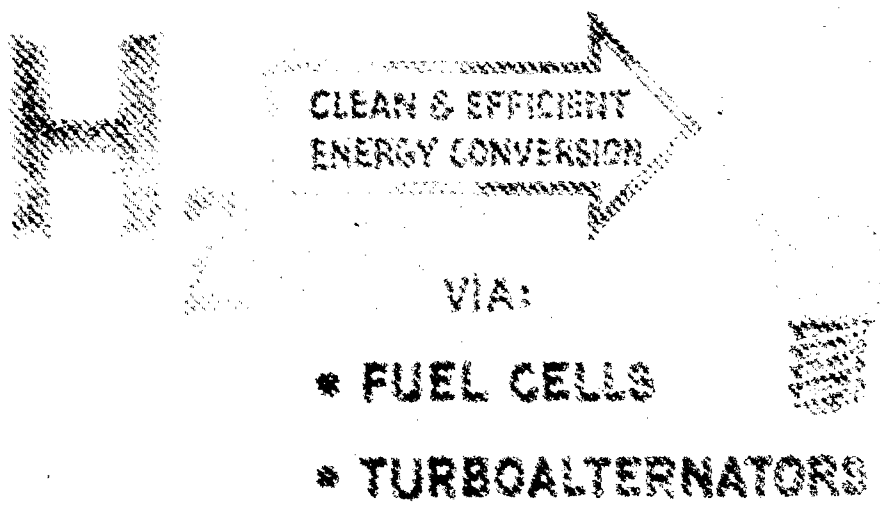
HYDROGEN – A UNIVERSAL FUEL AND FEEDSTOCK

Hydrogen can be distributed to Industrial, Commercial, and Residential customers in the same manner as our fossil fuel derivatives are today. Hydrogen is presently a widely used industrial feedstock for the fertilizer and petrochemical industries. It is used in metal refining and glass production. In the future it can be efficiently employed for space heating and cooking, using new appliances yet to be developed. Prototypes of these have already appeared providing impressive performance and acceptability.



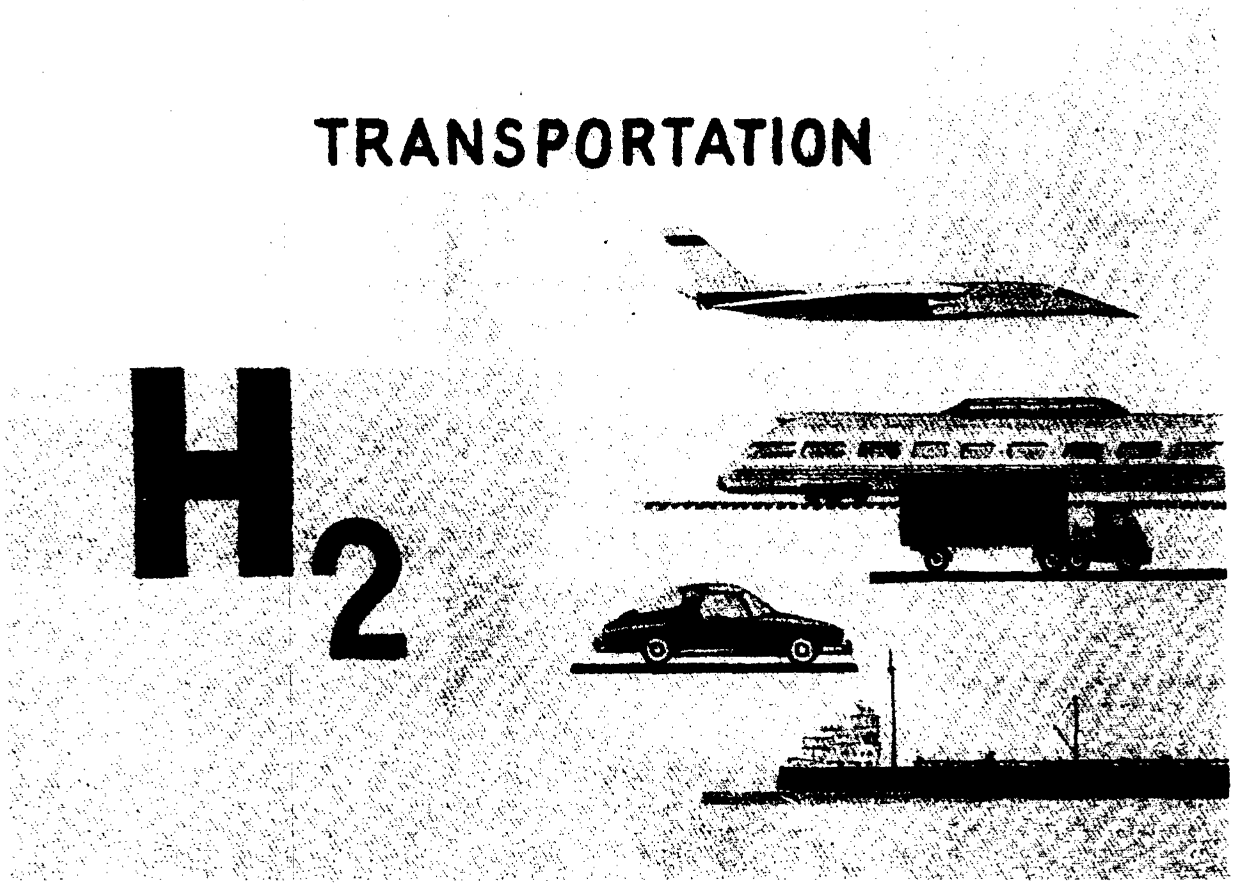
HYDROGEN-TO-ELECTRICITY: CLEAN, EFFICIENT CONVERSION

Hydrogen will be an important basic fuel for the Electricity Industry as well as a means of storing energy for peak utilization periods. Hydrogen is an ideal clean-energy fuel for gas turbines, fuel cells, and for advanced steam turbine generator concepts for maximizing generation efficiency.



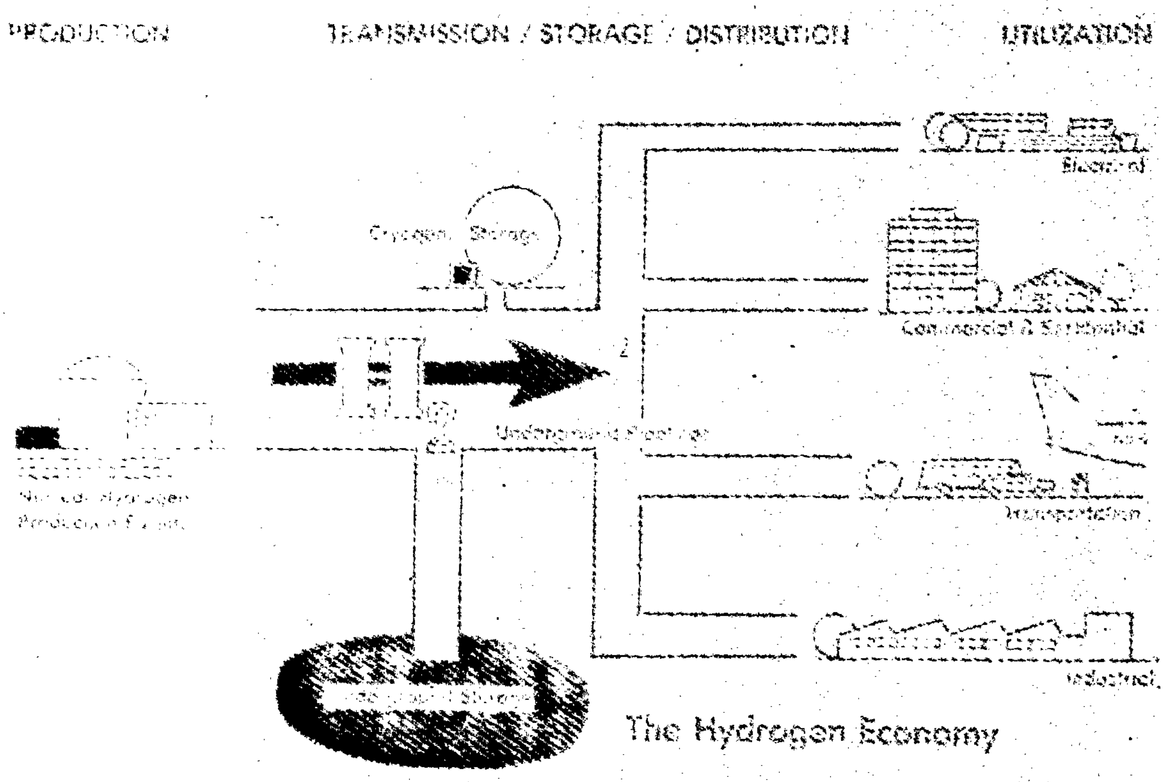
AN OUTSTANDING TRANSPORTATION FUEL

A very large and promising energy utilization sector which may evolve over to Hydrogen-energy is Transportation. Surface and Air Transportation uses as much as a quarter of the Nation's energy presently, mostly in the form of valuable petroleum-based fuels. Because it can be produced domestically and because it is so clean in use, Hydrogen could soon become the preferred transportation fuel.



A 'HYDROGEN ECONOMY'

Thus, an entire "Hydrogen Economy" can be envisioned on a National scale, and even on a Worldwide basis. All major energy-using sectors of our economy can conceivably convert to Hydrogen, with striking environmental benefits. Definitive studies of this prospect have shown no fundamental obstacles to production, transmission, storage, distribution, and utilization facets of such a Hydrogen Economy.



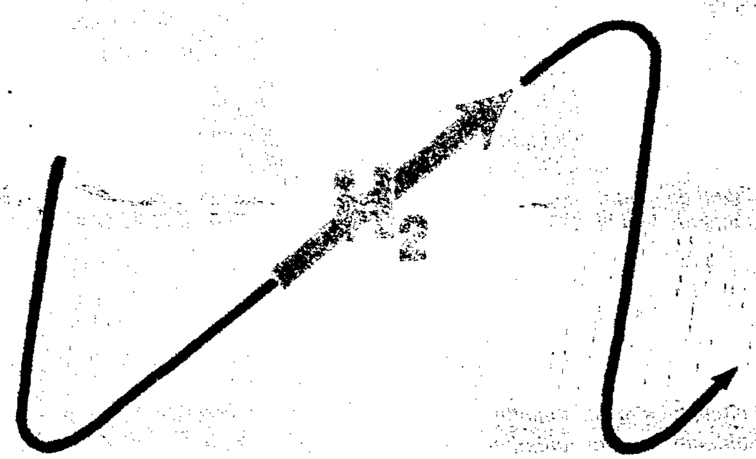
THE EXHAUST PRODUCT: WATER

Since water is the sole product of combustion of Hydrogen, emissions of sulfur oxides, hydrocarbons, carbon monoxide, particulates (smoke, soot), and even carbon dioxide are quite impossible. Methods of controlling oxides of nitrogen have been identified. Clearly, Hydrogen is the cleanest possible fuel.

NATURALLY AND RAPIDLY RECYCLED

In contrast to the present-day consumption of fossil-fuels, which require millions of years to renew, the hydrogen-water energy cycle is rapidly completed in a matter of days or weeks. Nature automatically and benevolently closes the cycle by returning the hydrogen, as water, to the World's oceans.

HYDROGEN
THE RECYCLABLE FUEL

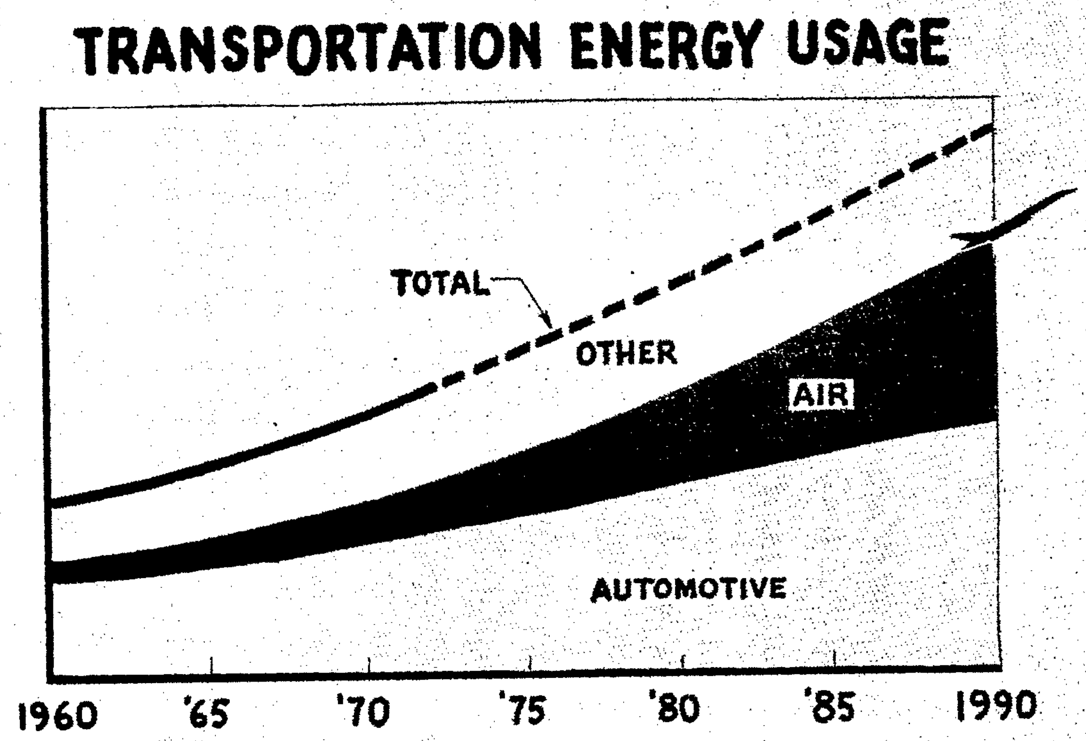


KEY TO SUPERIOR AIRCRAFT DESIGNS

Because Hydrogen has nearly three times the energy-to-mass ratio of normal aircraft fuels, commercial aircraft in the future may especially benefit in terms of improved payloads and range capability if designed for liquid hydrogen fuel. Though a bulky fuel, as evidenced in the large wing tip tanks in this model, Hydrogen's extreme light weight provides a compelling advantage to the aircraft designer. Its very low temperature characteristics provide no unsolvable problems as witness its widespread usage in our Space Program. For, quite literally, we went to the Moon on Hydrogen-energy.

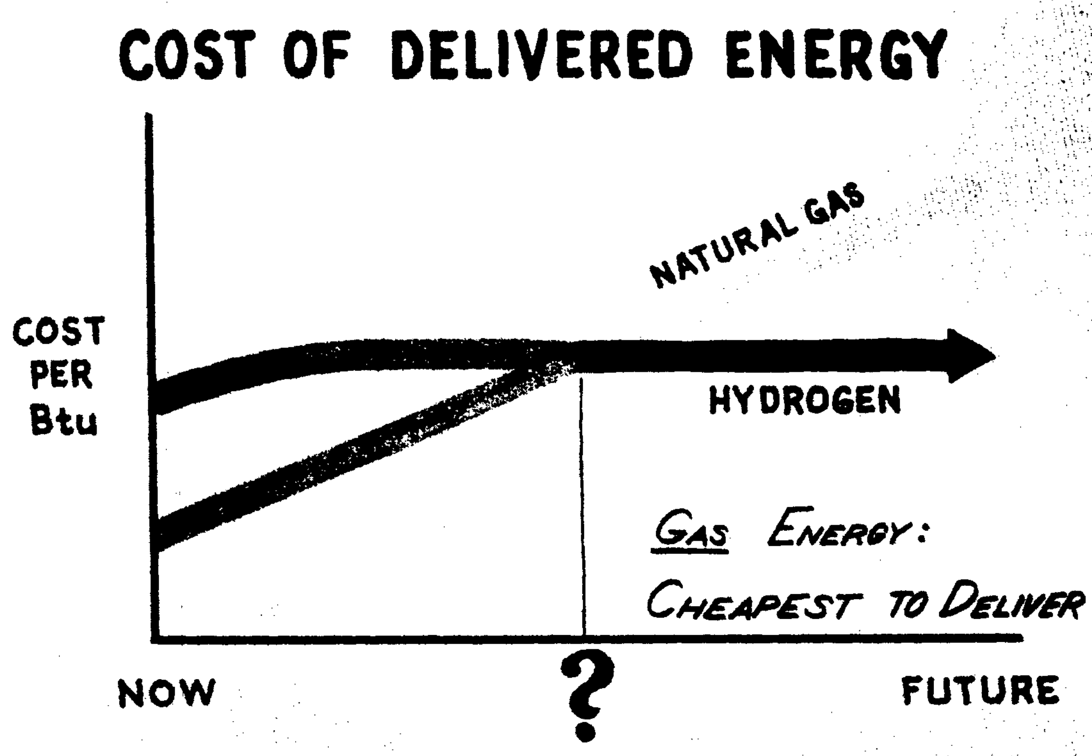
EVEN THE PRIVATE CAR WILL USE HYDROGEN

Surface transportation systems are also amenable to using Hydrogen-energy. Although aircraft energy consumption is the most rapidly growing area in transportation, automotive units continue to consume the majority of our limited petroleum-based fuels. Already demonstration hydrogen-powered vehicles are showing that even the private car can be safely and conveniently operated on hydrogen fuel provided an appropriate distribution system is established.



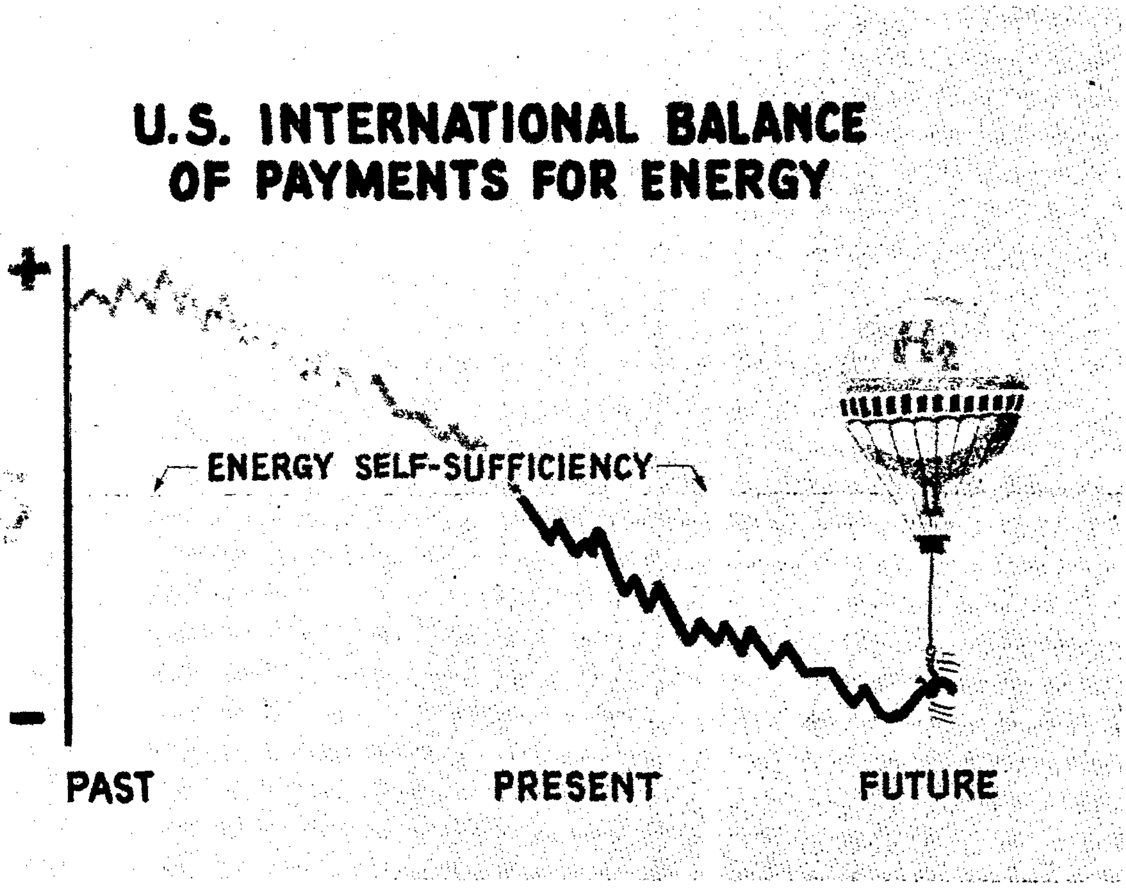
PRESENTLY EXPENSIVE – ULTIMATELY THE 'ECONOMY FUEL'

Today, Hydrogen is somewhat more costly to produce, transmit, and store than conventional fluid fossil fuels. Yet even today, Hydrogen produced initially from electricity could be served to the customer at slightly lower costs than the electricity itself. And, as fossil fuel prices rise due to increasing scarcity, at some point in the future, Hydrogen is expected to become the lowest priced energy form available. At this time, the Hydrogen Economy will become truly expansive.



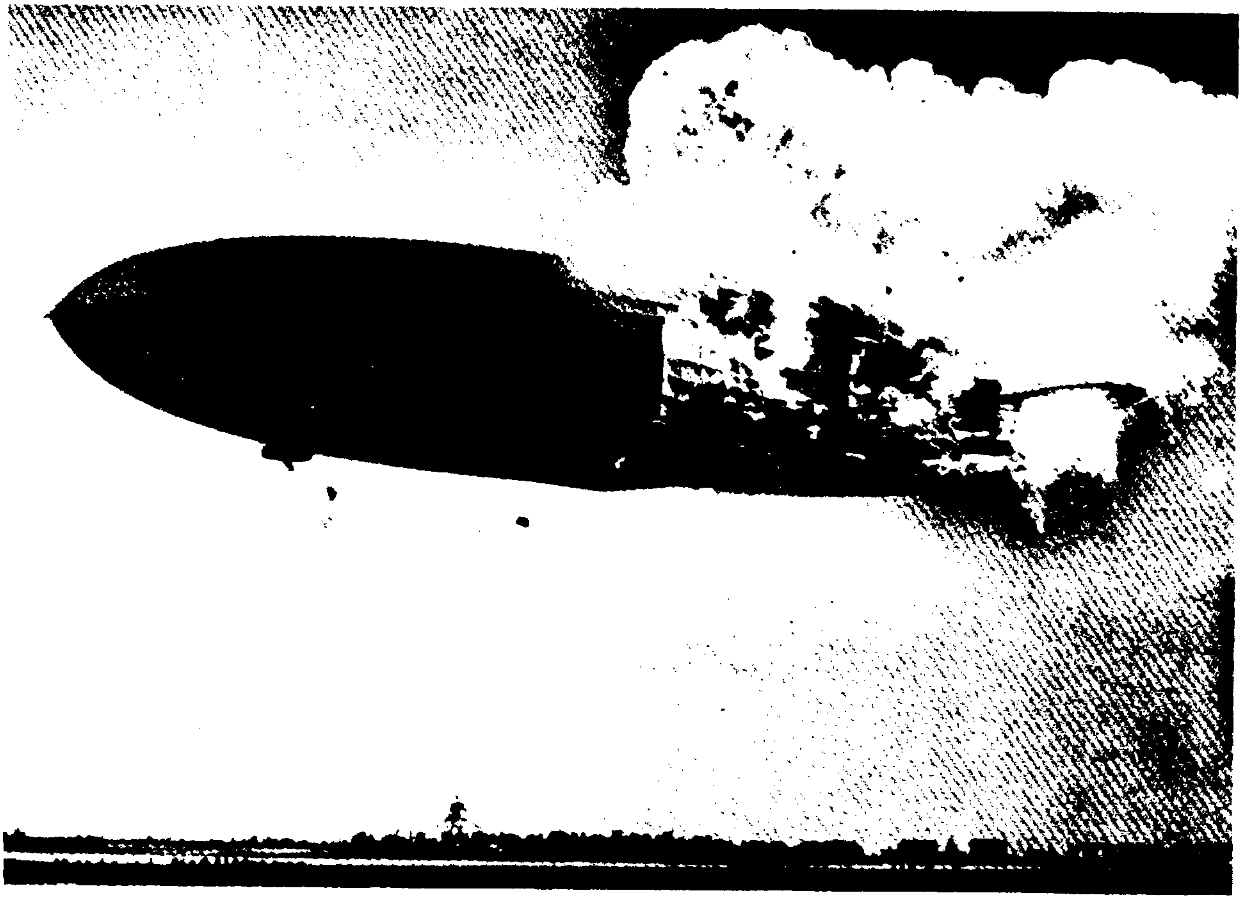
ONCE MORE, ENERGY SELF-SUFFICIENCY

With nuclear or solar energy production of Hydrogen, there may be no need to import natural gas and petroleum, at some point in the future. This will very favorably affect industrial nations' international balance of payments for energy. It could ultimately establish national energy self-sufficiency for all countries.



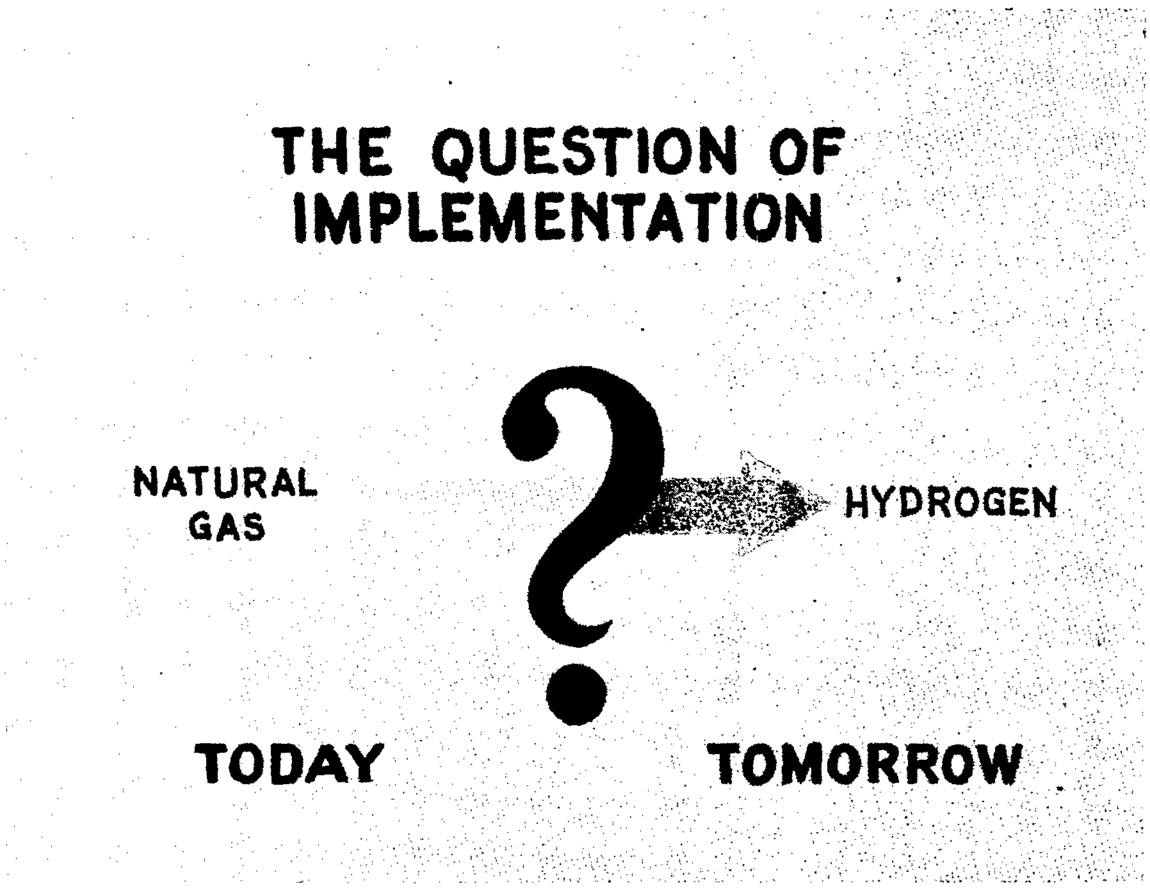
THE 'HINDENBURG SYNDROME'

Public acceptance of Hydrogen will depend on the elimination of the safety hazards long associated with its use. Technical facts must be separated from the unfavorable emotionalism concerning Hydrogen which has been termed: "The Hindenburg Syndrome." Hydrogen is in fact a safe fuel when properly handled. Safe-handling procedures have been well demonstrated by many Research and Development activities to date. A concerted program of public relations and education will carry this message to everyone.



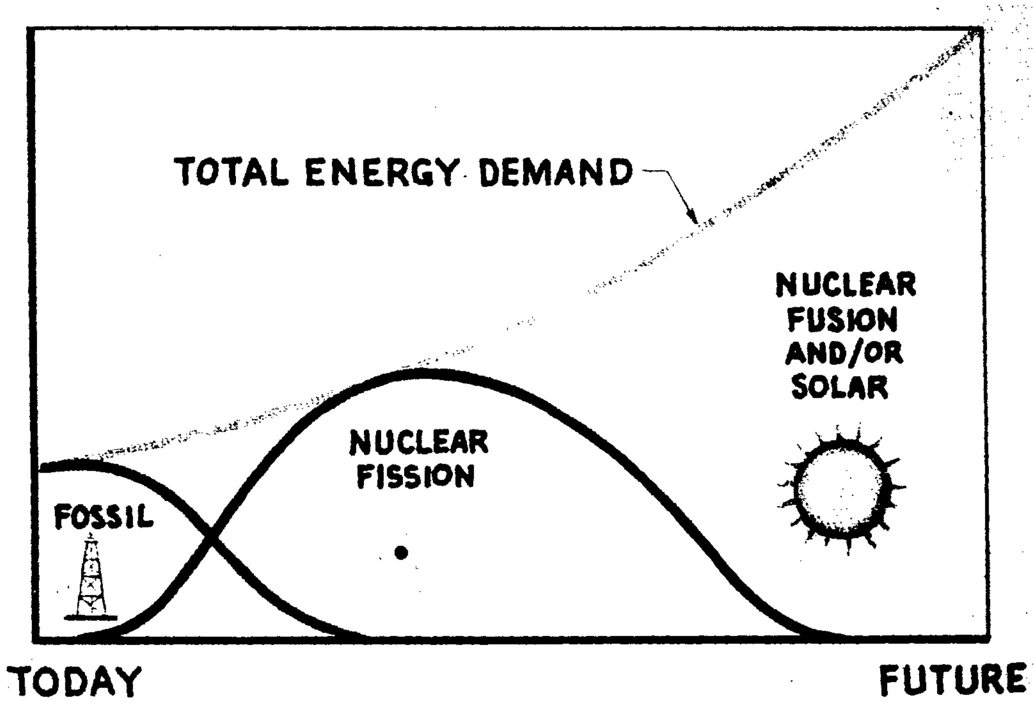
HOW, WHEN? FUNDAMENTAL QUESTIONS NOW BEING EXPLORED

How will the Hydrogen Economy be eventually implemented? What will be the eventual role of Hydrogen-energy in the overall "energy mix" of nations over the World? When will begin the conversion from fossil fuels to Hydrogen produced from non-fossil sources? These fundamental questions of long-range significance are being addressed today by Industry and Government planners. Adequate research and demonstration programs must be initiated and supported with a studied sense of urgency.



HYDROGEN END-USE PERMITS AN EVOLUTION IN NEW ENERGY SOURCES

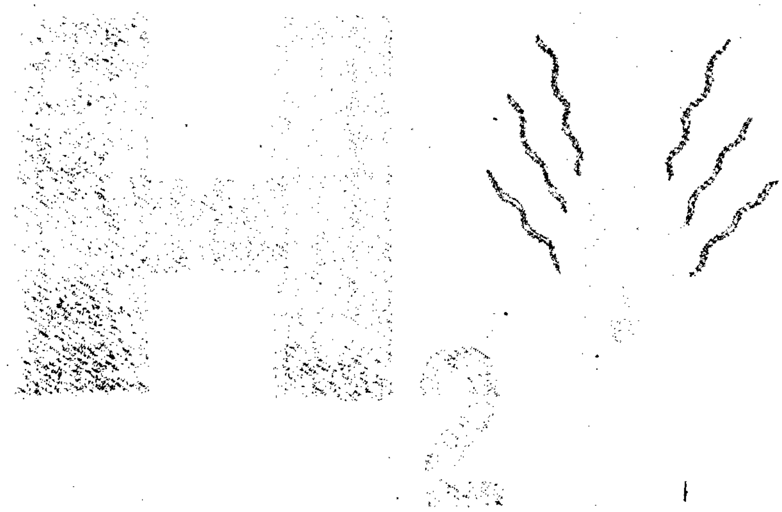
A smooth and orderly transition from today's fossil fuel sources of energy to eventual nonfossil primary sources is, as noted, an essential step. Nuclear fission energy, which is likely to be the first available nonfossil source, may be supplanted in time by controlled nuclear fusion, solar energy, or both. Hydrogen-energy is uniquely capable of being produced from any of these sources, and others as well. This will permit source-transitions to occur without a corresponding series of dislocations in the delivery and end-use of energy.



IN THE TRADITION OF THE WORLDWIDE ENERGY INDUSTRY. . .

In a tradition of serving clean, abundant energy to its customers and constituents, Energy Industry/Government teams around the World are actively planning for the future and the changes in energy patterns which are inevitable. With expanded Research and Development, Public Education, and continued devotion to its proud tradition, the Energy Sector will continue its leadership role in the coming age of the Hydrogen Economy.

THE HYDROGEN ECONOMY



SESSION III

ENERGY SOURCES – PART II

Chairman: Mr. Bernard Gerber
Edgewood Arsenal

REVIEW OF POWER FROM THE WIND

by

Mr. Abraham Flatau
Edgewood Arsenal, Maryland

INTRODUCTION

In presenting a review of "windpower," I should like to clarify several key points. First, I do not claim to be an expert in this field. I am an aerodynamicist, whose background has included extensive experimental research in autorotating configurations. This has brought me into contact with certain windmill devices and accounts for my interest therein.

Secondly, I intend to provide you with some background and then indicate what is presently underway in the field of power from the wind. I shall *not* discuss the complete electrical generating and storage system aspects.

BACKGROUND

The use of power from the wind goes back to ancient times. Windmill designs have evolved in a very gradual fashion. For example, history reveals that in ancient Persia the windmill designs were of a type shown in figure 1.* The interesting features of the Persian design relate to the fact that, in addition to having a vertical axis of rotation, the prevailing winds were such that fixed sidewalls could be built. At the rear was a smaller opening. This produced a venturi effect. Also the Persians built a curved wall adjacent to one side of the windmill so as to initiate the rotation in a predetermined direction.

Several European designs are shown (figures 2 to 4). Figure 3 is shown as a matter of historical interest. It is a Rembrandt etching and shows how gradually we have advanced in the basic windmill design. Note that the rotational axis of each of these was horizontal. That is, the blades act in a manner similar to that of a conventional aircraft propeller. With the exception of a design from Scandanavia, which I shall describe and discuss later, the majority of windmills in use today are of a propeller type, although the number of blades has been reduced and the blade design is based on the more up-to-date aerodynamic technology. An early example, presently used, is shown in figure 5. Another modern design, based on the propeller approach, is shown in figure 6. From basic propeller theory, one may select the key performance relationships leading to current conventional windmill designs. Figure 7 indicates the parametric relationships.

In the past half-century, there was only one major effort in the United States to produce a large amount of electricity by wind power.[1] From 1941 to 1945, a 175-foot-diameter, two-bladed propeller atop a 110-foot tower built on a 2,000-foot hill in Vermont (Grandpa's Knob) turned an alternator. The system was designed for average wind speeds of 24 mph and to develop 1,250 kw for transmission lines. However, winds averaged 17 mph and, in 1945, a blade was thrown. The project was then discontinued as it was considered a failure.

Recently, NASA announced that it is designing a 100 kw wind generator with plans for constructing and testing in 1975. NASA is also conducting studies which hopefully will lead to a realistic evaluation of wind generators as related to our nation's energy needs.

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*Figures placed at end of text.

[1] Putnam, P. C. Power from the Wind. D. Van Nostrand Company, Inc. 1948.

CURRENT STATUS

However, what of advancing technology? Earlier, I mentioned a Scandanavian design. This is the simple autorotor designed by Savonius, a Finnish engineer, in the 1920's (figure 8). Note that we again see a vertical rotational axis. Several of the Savonius' characteristics are worthy of consideration. First, it will commence rotation with the wind at any azimuth (or direction). Secondly, it will initiate rotation at very low wind speeds. Also, depending on aspect ratio and the blade positioning (relative to each other), a very high rotational rate can be developed as compared to conventional propeller windmill designs. Detailed flow field into and around a Savonius design, as well as other autorotor designs, are shown in the short movie. This movie was taken in a wind tunnel using smoke streams to obtain the flow field characteristics.

Recently, NASA showed another windmill design having a vertical axis of rotation (figure 9). It appears to be simple and to be based on achieving high tip speeds which are practical today in light of modern materials and fabrication techniques.

In the final analysis, we will come up against the key decision maker-cost, or economics. Two costs are involved: the first cost (or the ownership cost) and the operating cost. The first cost is easy to define – what does it cost to acquire and install the windmill? One commences to see that as modern technology is applied to this power field, including the cost savings that come from mass production, the ownership cost could be significantly reduced. Present wind-power system costs are in the general order shown in figure 10. However, the operating cost must be determined by actual system use and is also a function of the engineering design and hardware reliability. A simple list of requirements for the household is presented in figure 11.

RECOMMENDATIONS

Granted that the power generation level of windmills is far down on the energy spectrum (figure 12), it has been shown that windmills are capable of producing sufficient power to meet the basic household needs of small families, at least in those areas of the country having favorable wind conditions. The use of windmills to provide 10% to 15% of our total household power needs in this country would be meaningful in an era of energy conservation. Experimental research must be done in a rapid and efficient manner to explore the potential of new windmill designs. The technology exists for obtaining advanced windmill designs which are based on aerodynamic research and development in conjunction with modern materials and more efficient magnets and alternators. Also, more detailed or selective meteorological data is required. There is a need to research, develop, and produce wind generators that are competitive with fossil fuel systems on a cost effectiveness basis. This could result in low-cost efficient power generators for home use. It should also be kept in mind that while fossil fuel may not be with us forever, the availability of wind and power therefrom should be with us as long as our galaxy remains in its near present form. Let us not merely tilt with the potential of power from the wind (figures 13 and 14). A start has been made in the form of the work initiated by the National Science Foundation and NASA.[2] We are in need of solid, well-planned, short- and long-range programs whose payoff will not only benefit us in our lifetime but provide a promising future for our children and the generations thereafter.

[2] NSF/NASA. Wind Energy Conversion Systems. NSF/RA/W-73-006. December 1973.

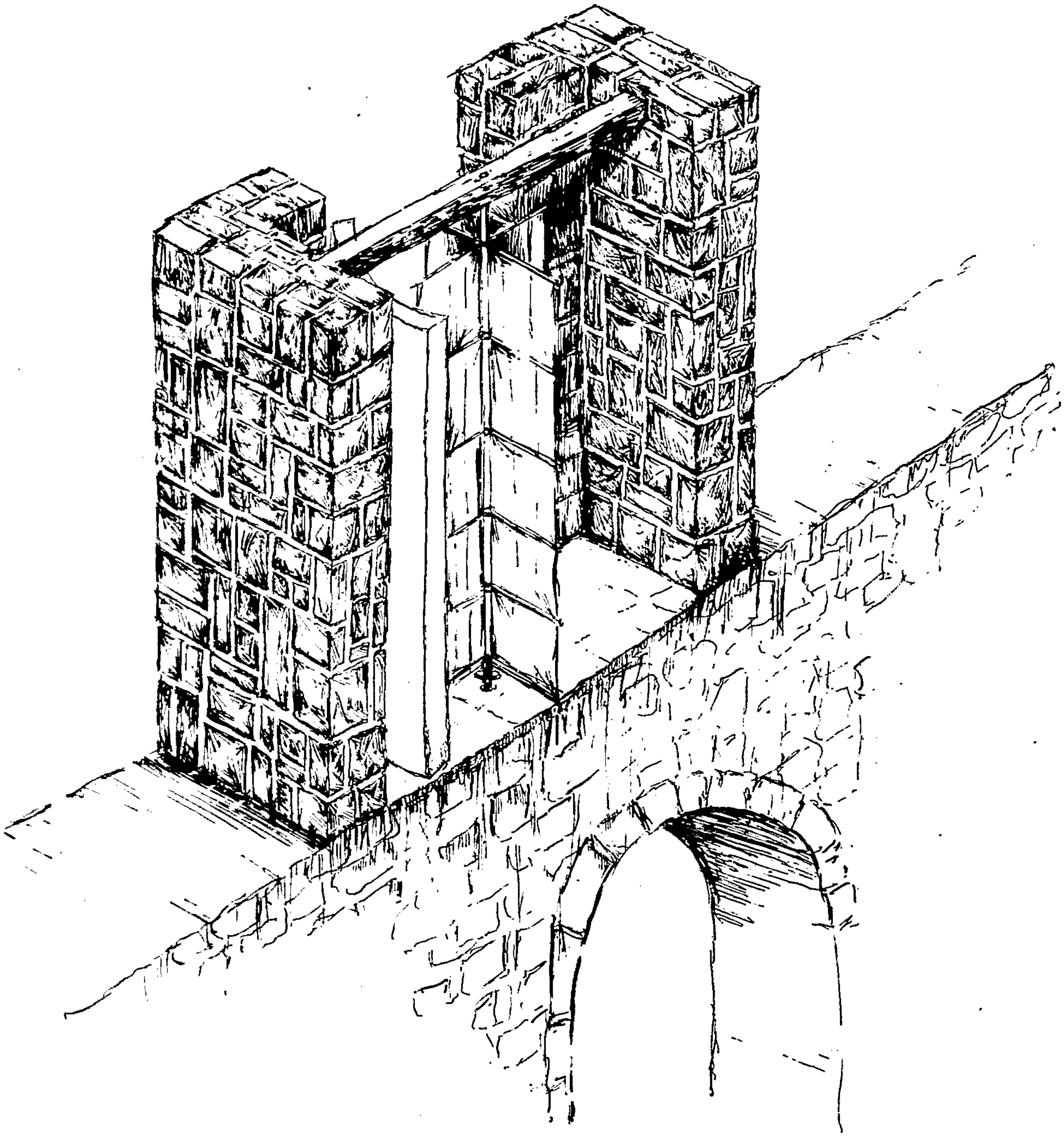

Figure 1. Persian Windmill

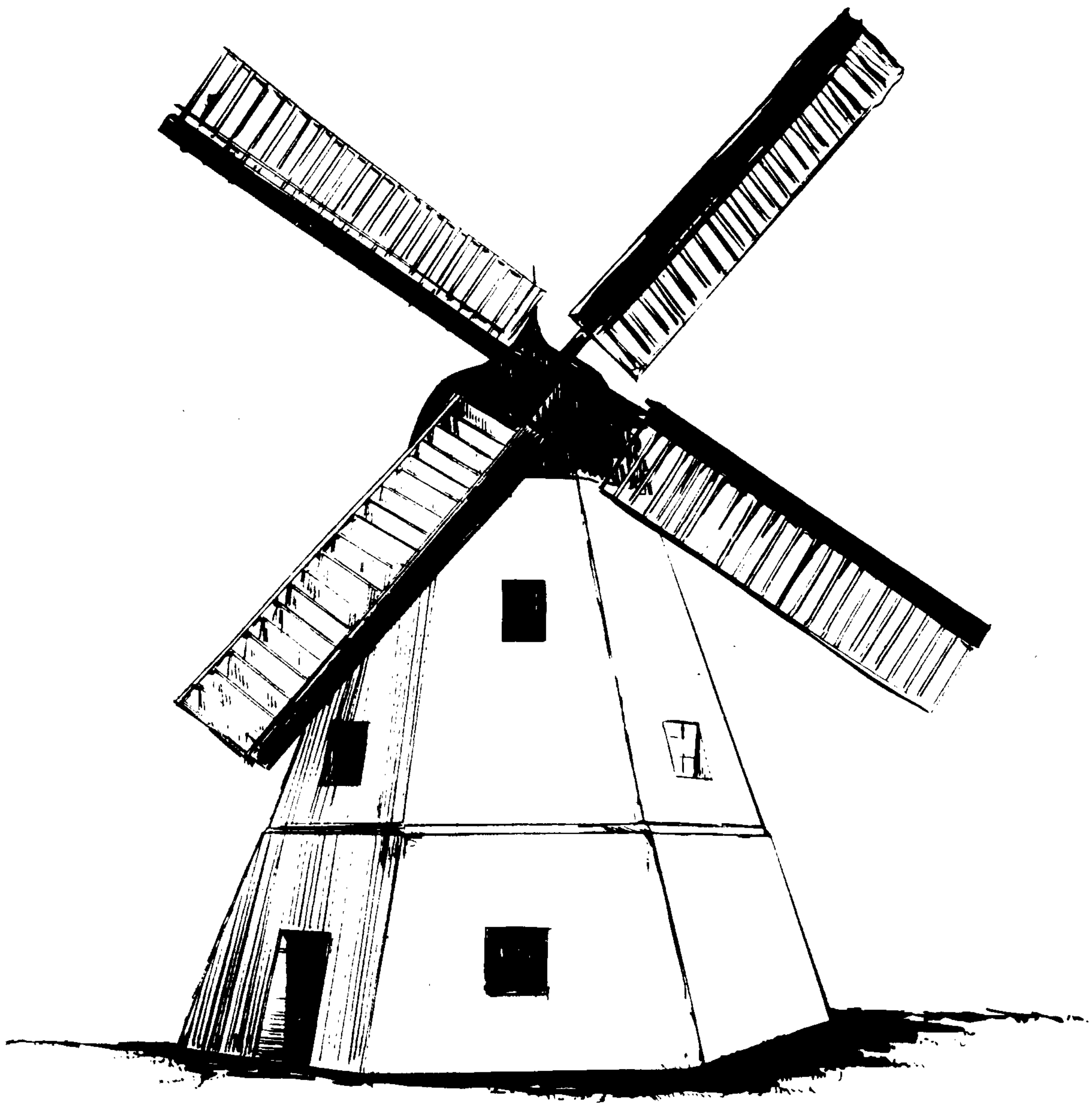

Figure 2. Danish Windmill

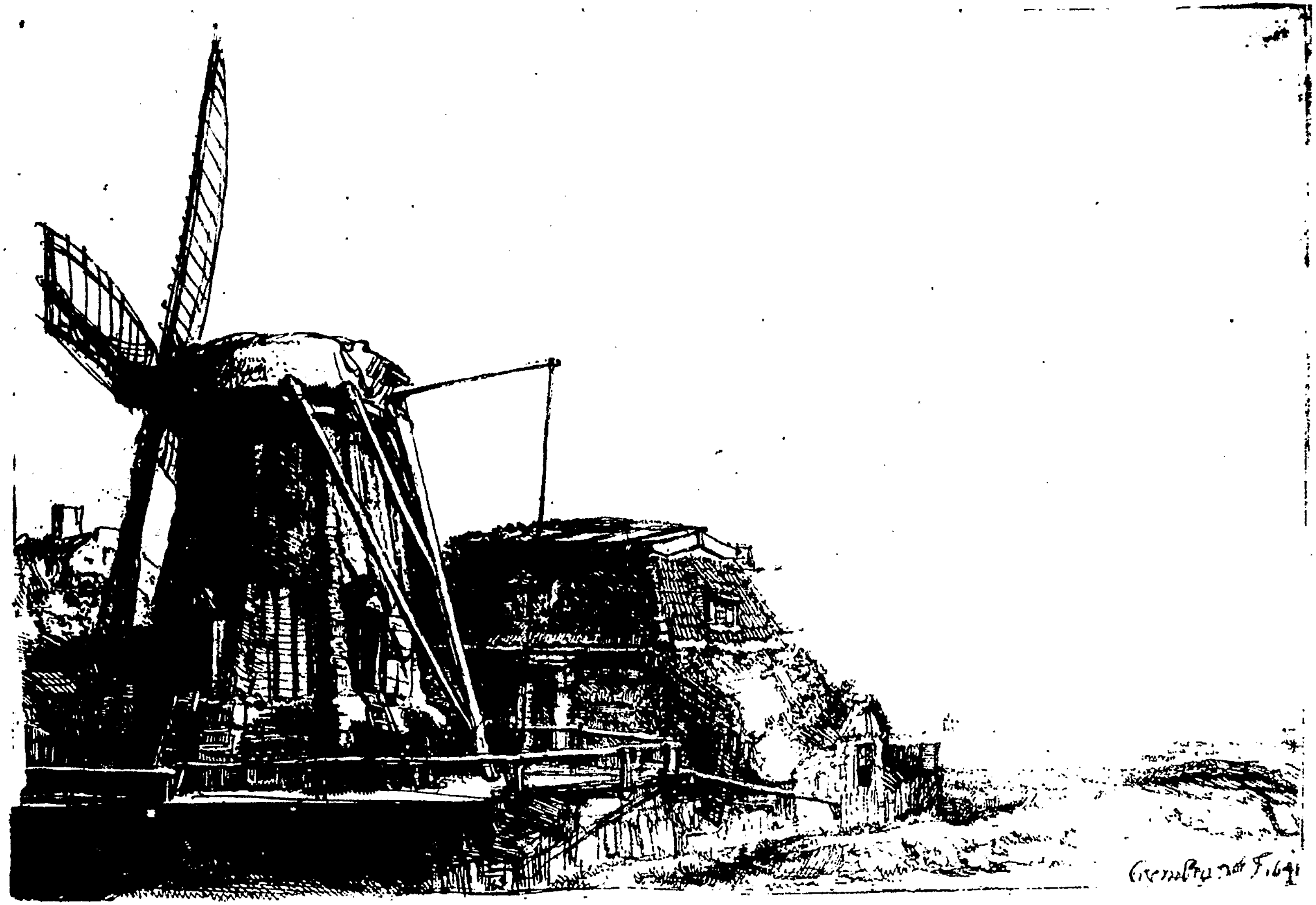

Figure 3. Rembrandt Etching of a Windmill

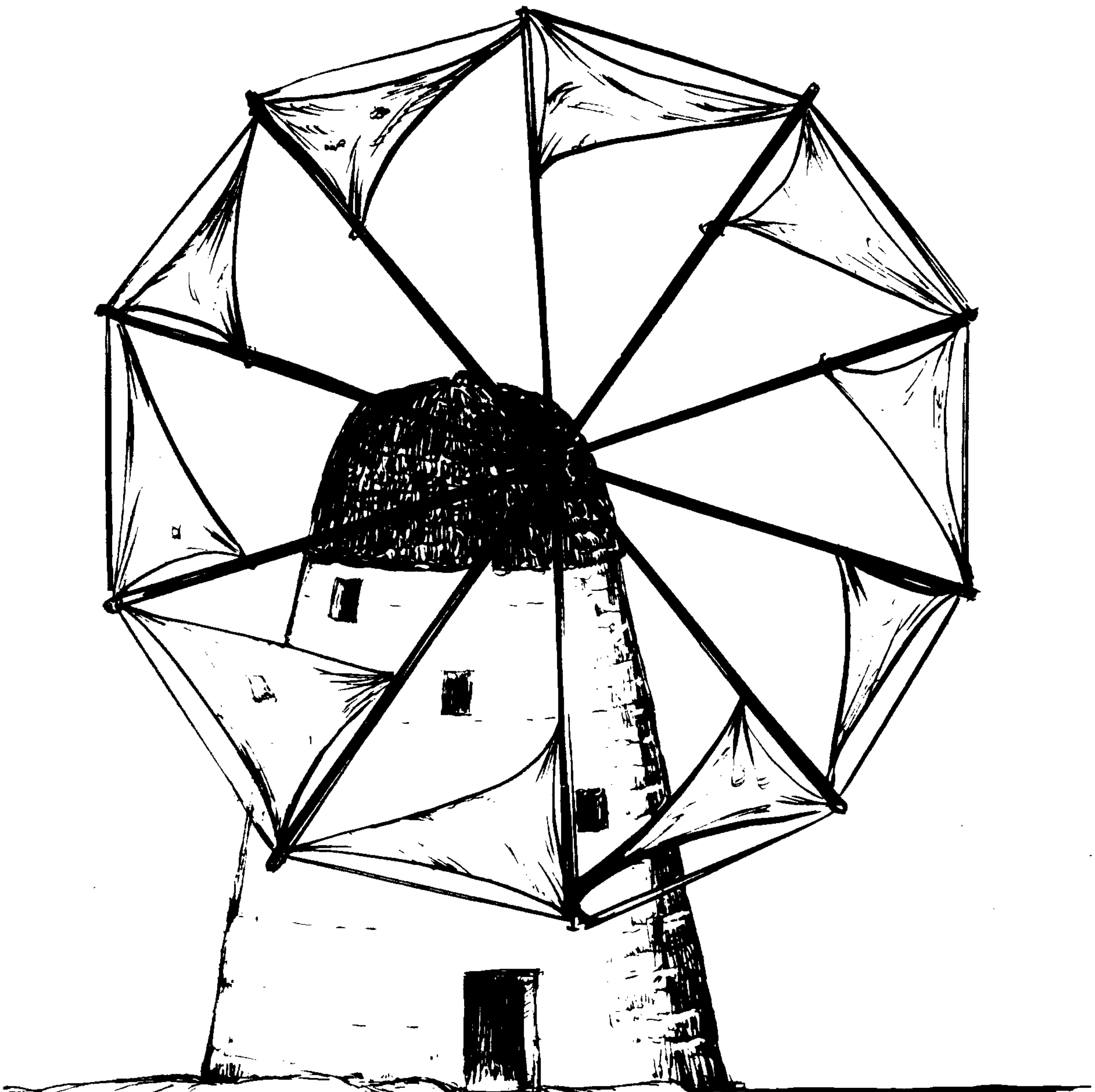

Figure 4. Greek Windmill

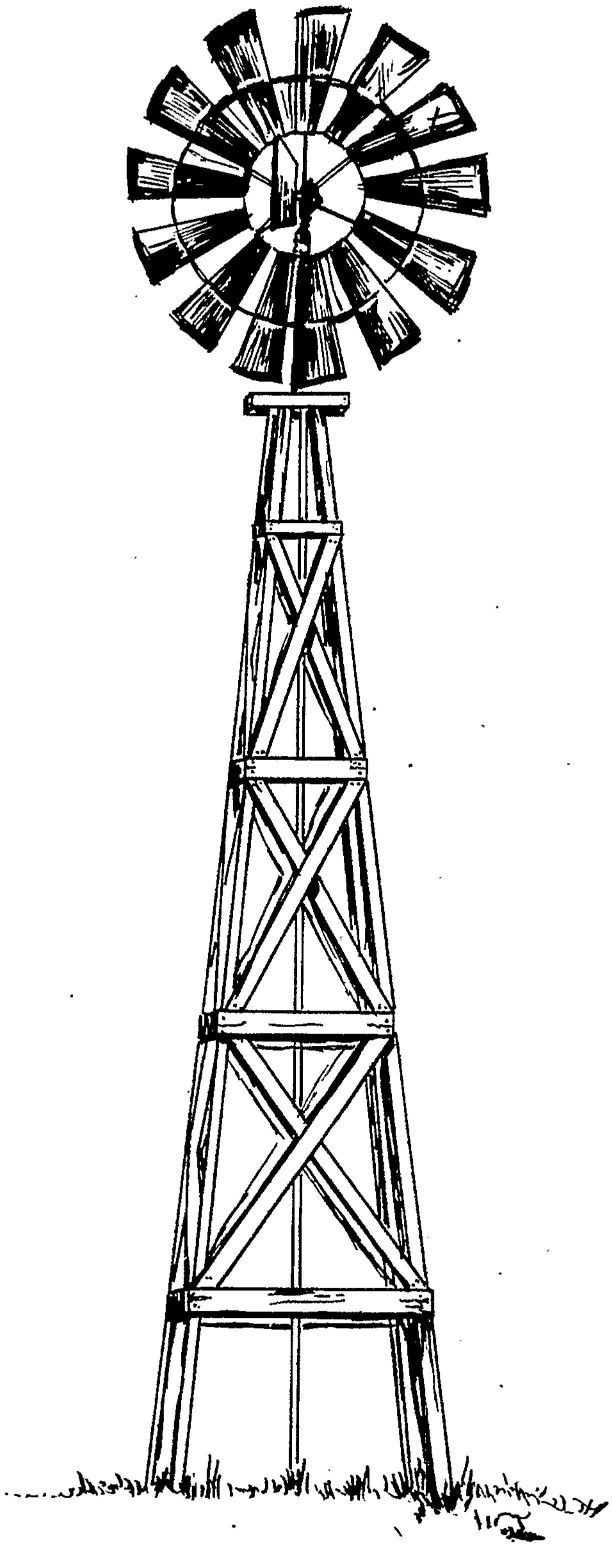

Figure 5. Early American Windmill (Still in Use)

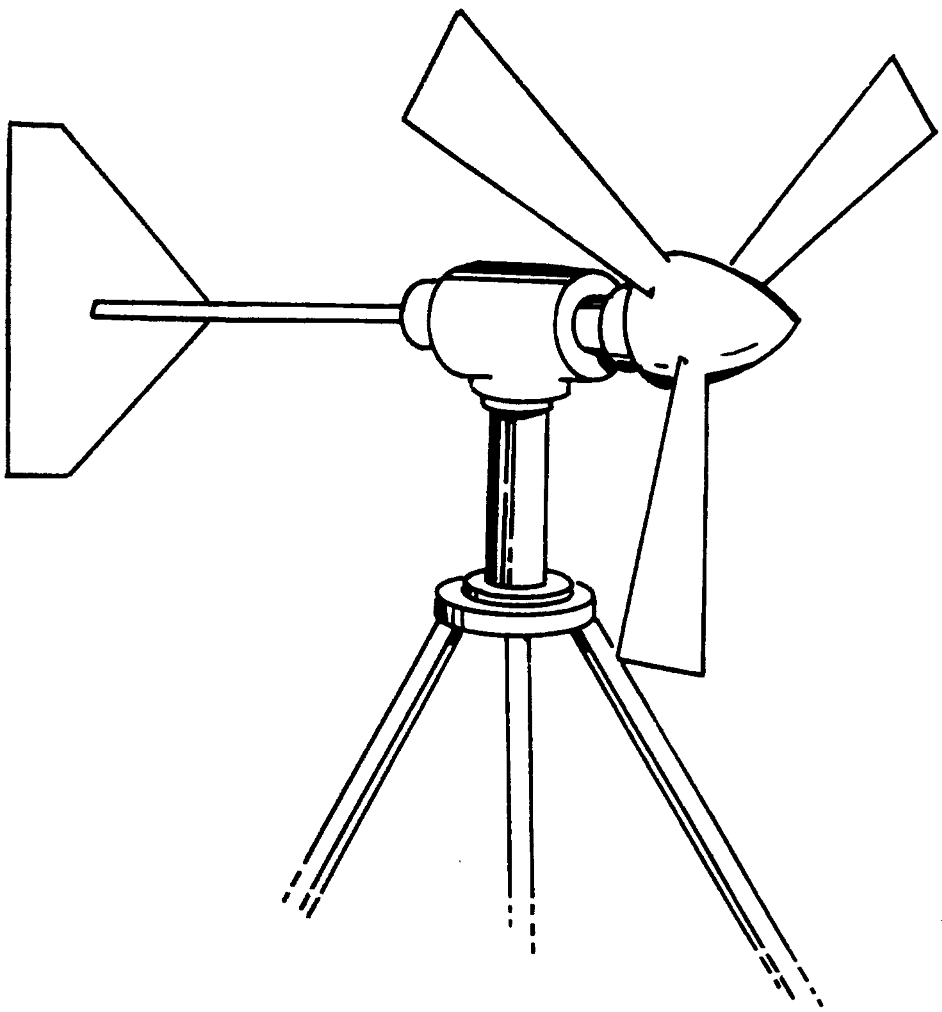

Figure 6. Later American Windmill

$$\text{POWER (P)} \sim [\text{WIND VELOCITY (V)}]^3$$

OR $P \sim V^3$

AMERICAN MULTIBLADE ~ 30% EFFICIENT

DUTCH 4 ARM ~ 16% EFFICIENT

HIGH SPEED PROPELLER ~ 42% EFFICIENT

$$\text{POWER (P)} \sim [\text{BLADE DIAMETER (D)}]^2$$

OR $P \sim D^2$

$$\text{COST (\$)} \sim [\text{BLADE DIAMETER (D)}]^3$$

OR $\$ \sim D^3$

Figure 7. Basic Relationships

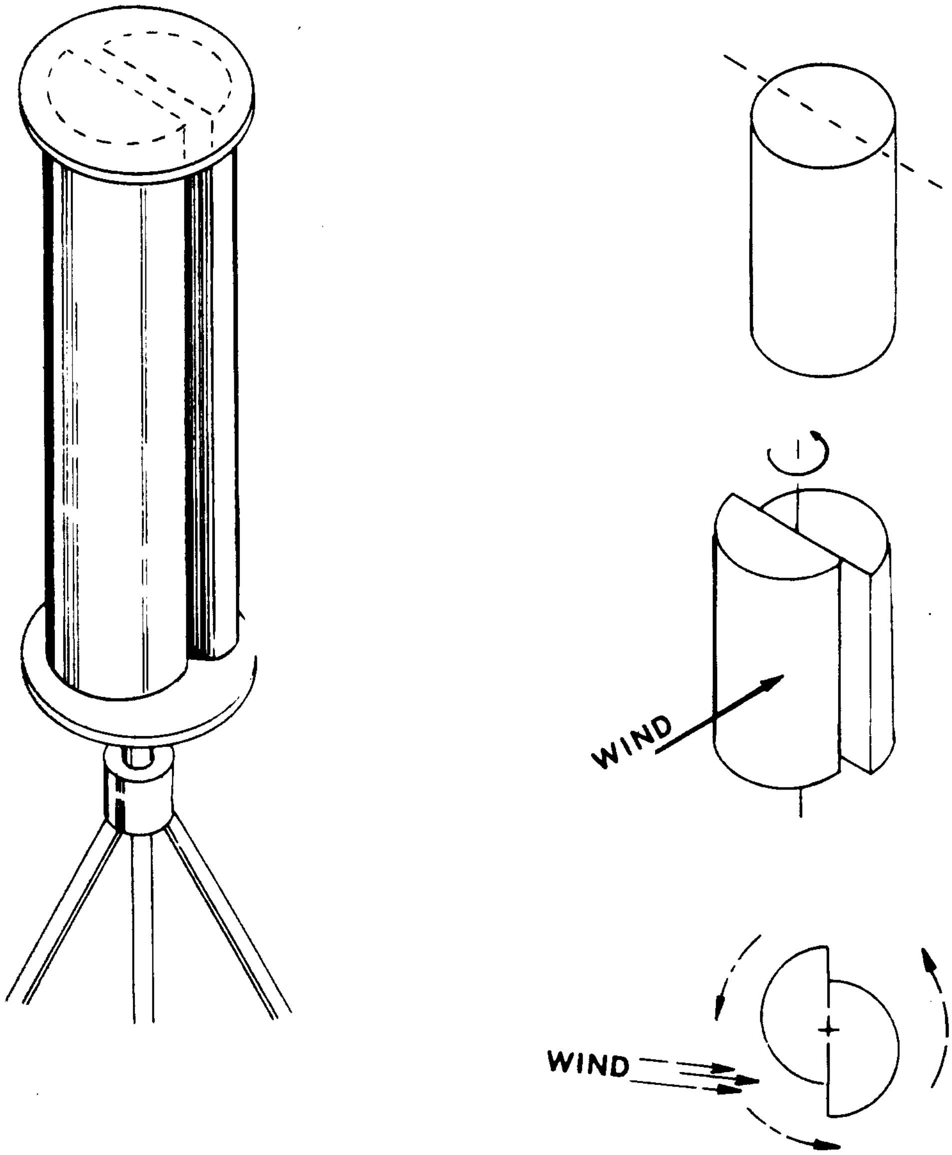

Figure 8. Savonius Autorotor

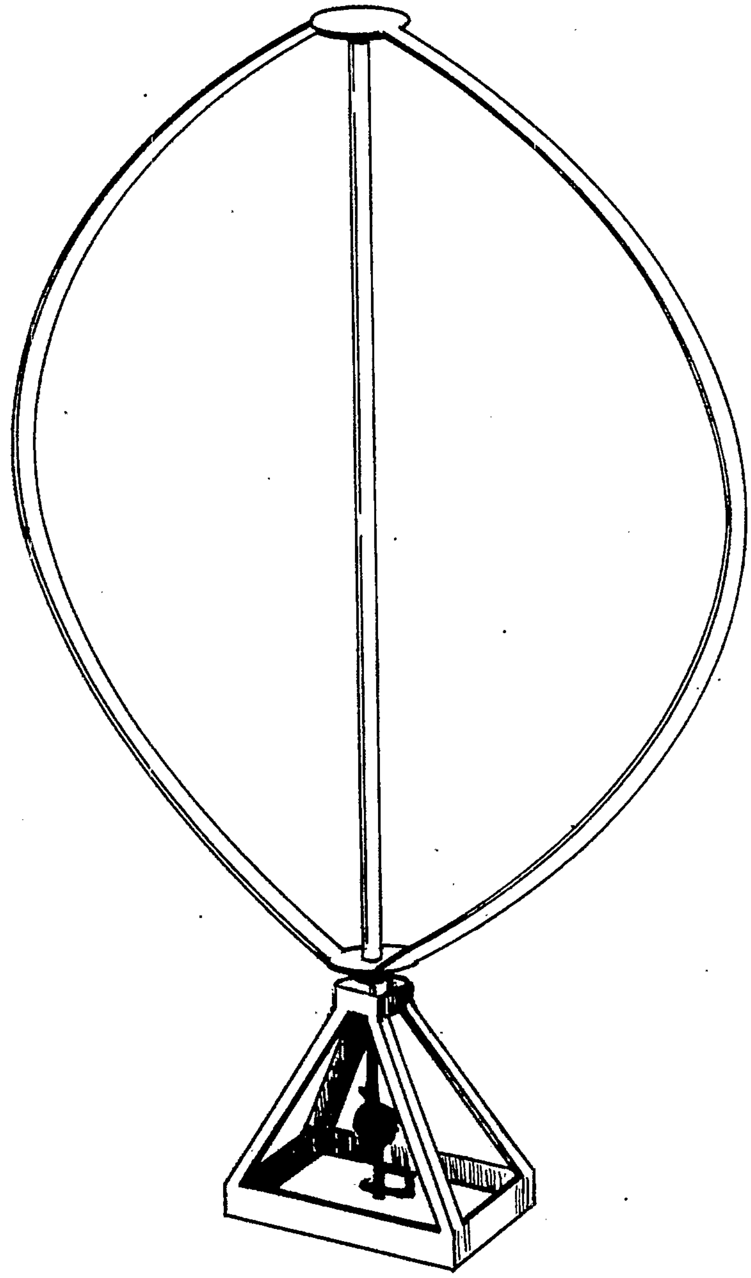

Figure 9. NASA Windmill Design

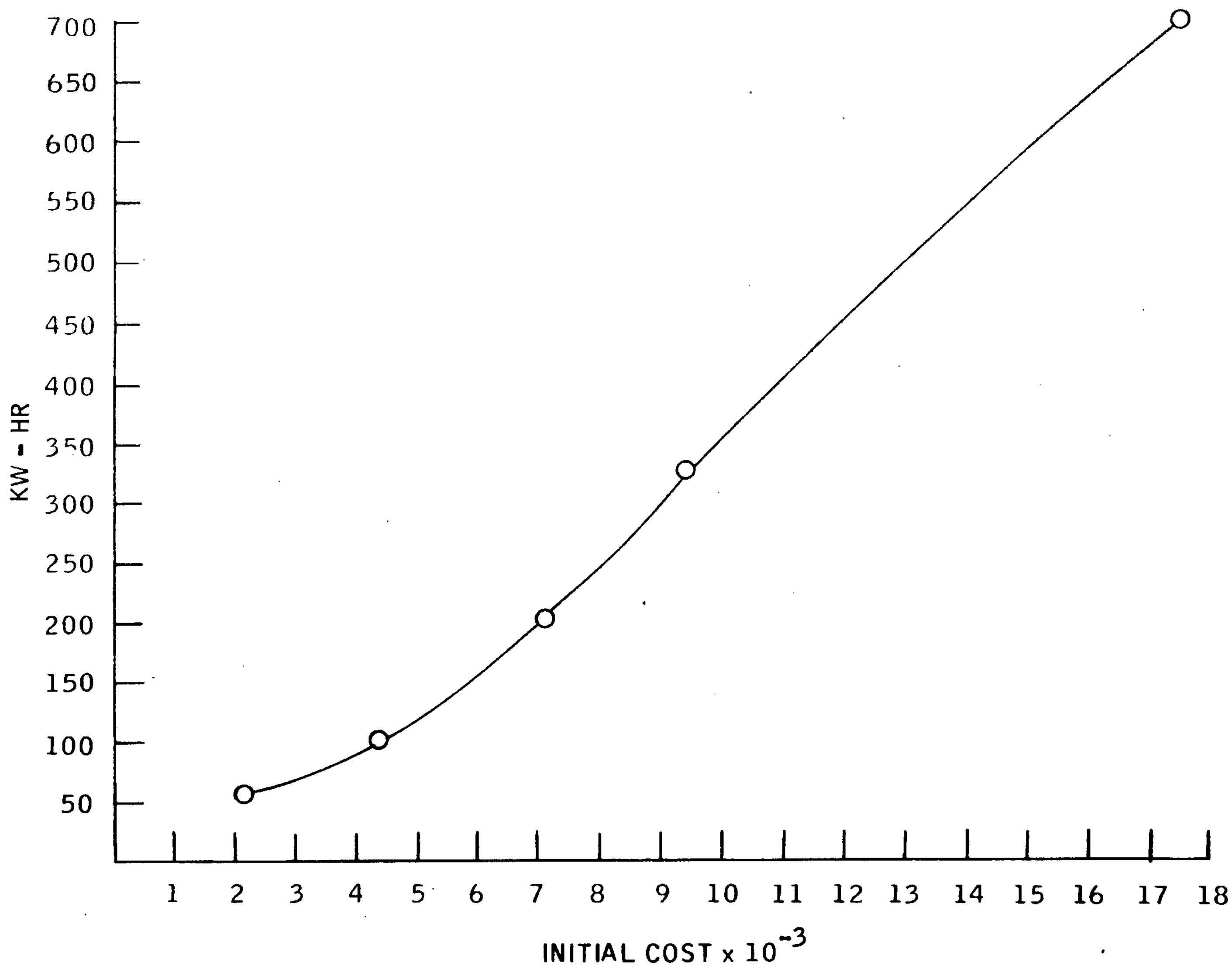

Figure 10. Initial System Cost for 115-V A.C. System

APPLIANCE	POWER IN WATTS	TIME USED PER MO. IN HRS	TOTAL KW-HRS PER MONTH
AIR CONDITIONER (WINDOW TYPE)	1,566	74	116
FAN (ATTIC)	370	65	24
FREEZER (15 CU. FT.)	340	290	100
FREEZER (15 CU. FT.) FROSTLESS	440	330	145
LIGHT BULB (75-W)	75	120	9
LIGHT BULB (40-W)	40	120	4.8
OIL BURNER, 1/8 HP	250	64	16
RECORD PLAYER	60	50	3
REFRIGERATOR-FREEZER (14 CU.FT.)	326	290	95
REFRIGERATOR-FREEZER (14 CU. FT.) FROSTLESS	615	250	152
TELEVISION - B & W	237	110	25
WASHING MACHINE (AUTO)	512	17.6	9
WATER HEATER	4,474	89	400
WATER PUMP	460	44	20

Figure 11. Basic Home Power Requirements (115-V System)

JET AIRPLANE	30,0000HP
AUTOMOBILE	100 HP
DUTCH WINDMILL	2 HP
REFRIGERATOR	1/2 HP
FLOURESCENT LAMP	1/20 HP
TRANSISTOR RADIO	1/1000 HP

Figure 12. Basic Power Expenditures

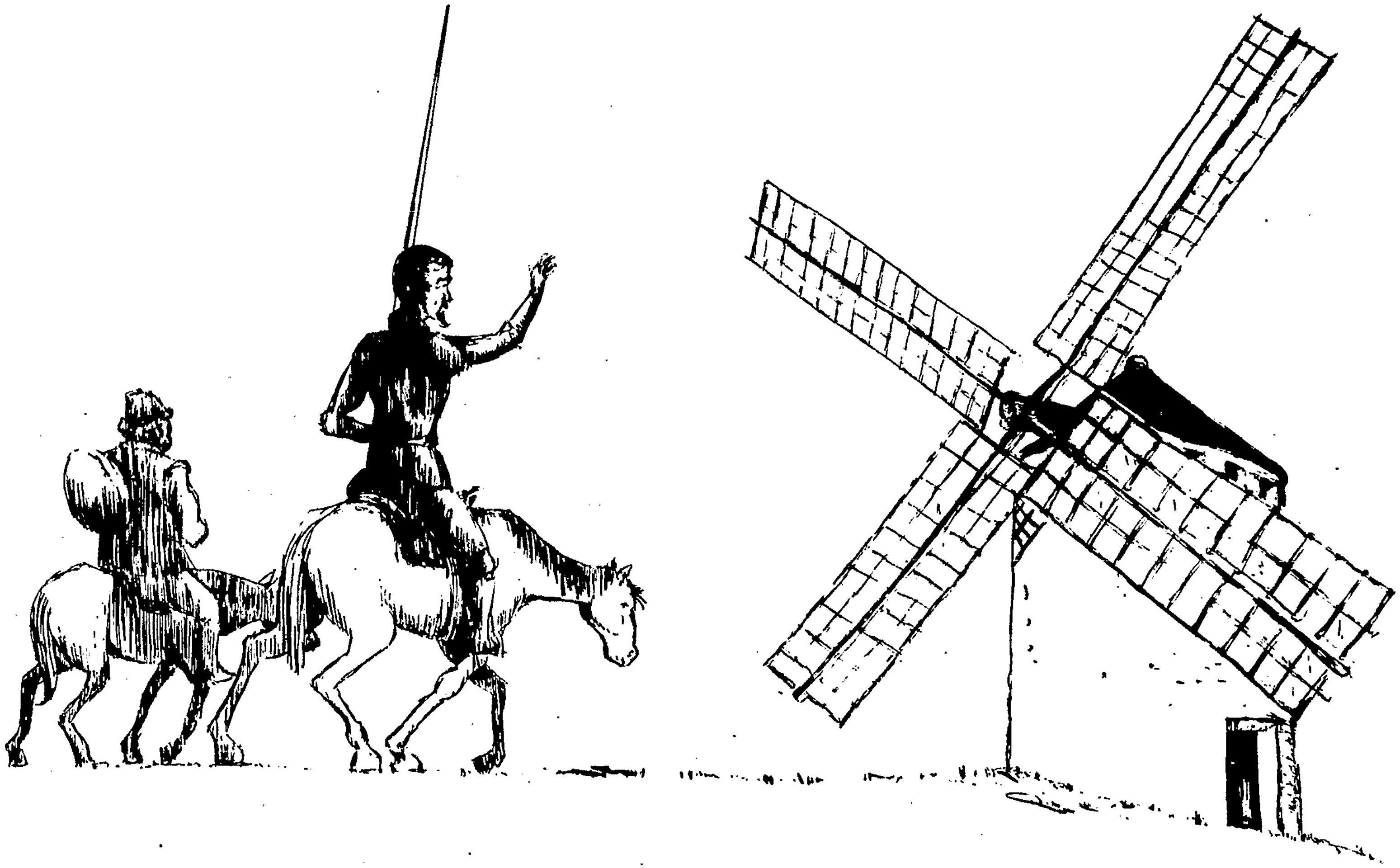

Figure 13. Unused Power Source, Early Model

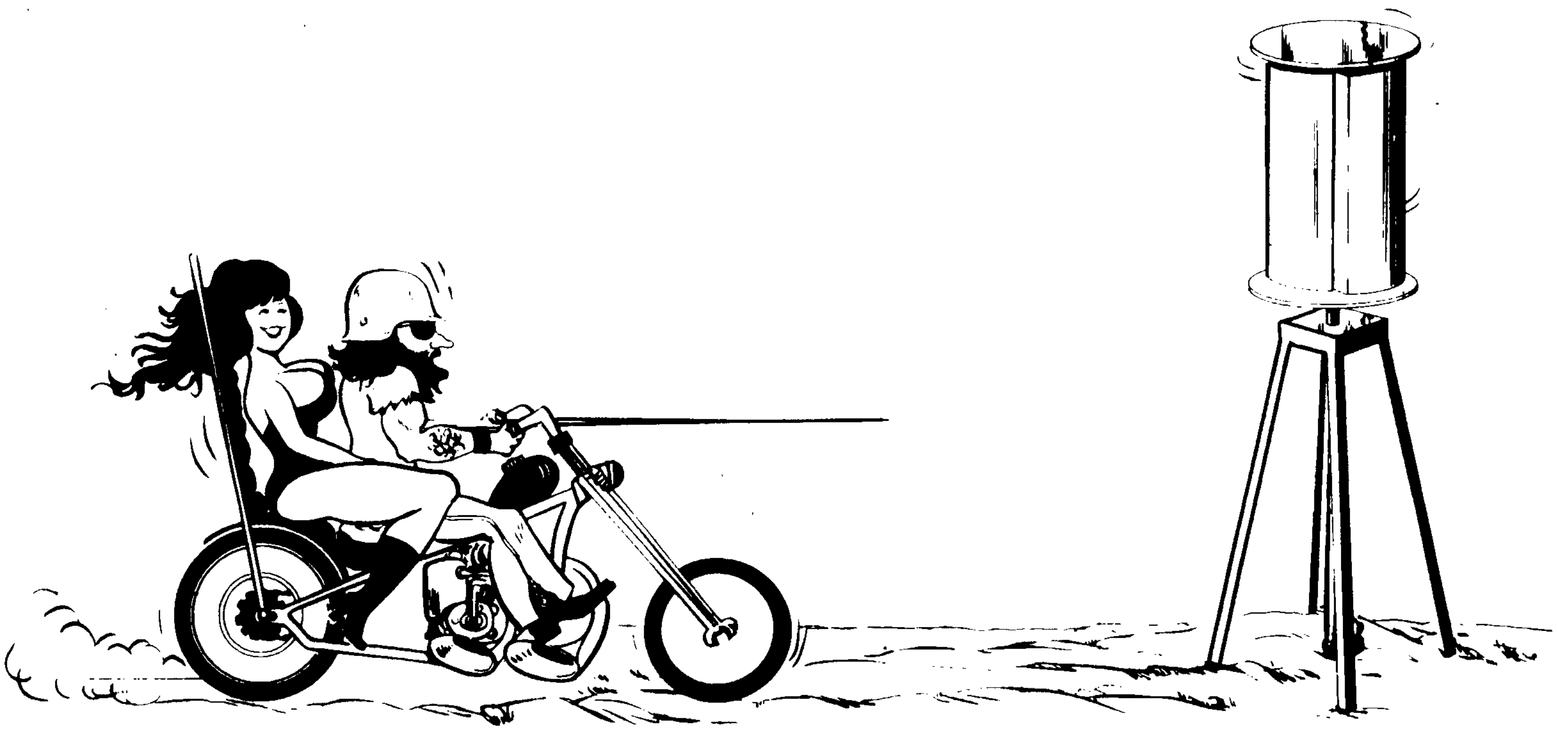

Figure 14. Unused Power Source, Later Model

BIOCONVERSION OF SOLAR ENERGY – PHOTOSYNTHESIS

by

Professor Allan H. Brown
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Photosynthesis is a patently effective energy trap which captures sunlight and stores it as chemical potential energy. This has led to various optimistic predictions about man's capacity to produce vastly increased yields of either food or fuel by novel technologies employing some exotic high-yielding crop or algal strain.[1,2] The simplistic view is that an ideal plant species photosynthesizing under optimal conditions would harvest the sun's energy on a large scale at high efficiency. The optimism has a sound basis, even if it may seem fanciful in detail, for the plants' invention of photosynthesis – a truly remarkable event in the history of the biosphere – has been exploited by all organisms including man because it is a remarkably efficient power source. Why should not man, with his modern technical sophistication, maximize its utilization for his ever-growing energy needs?

Energy from the sun is free in the sense that, however much it may cost us to use it, the supply itself is assured far into the future, and it is subject neither to boycott nor to price escalation. Moreover, it is a large supply; it exceeds by nearly three orders of magnitude our total energy consumption today.

There are several physical ways of making use of solar energy directly or indirectly. The energy can be converted to heat and used on small or large scale for solar heating. The radiation can be focused to produce locally temperatures which are high enough for efficient power generation or metallurgical processes. It can be converted with good yield by solar cells directly into electrical energy. Alternatively, the radiation can be transformed by photosynthesis into the chemical potential energy of organic compounds. This last conversion, photosynthesis, is the only biological process on the list.

Of course, all along we have been using some of the sun's energy which has been converted by photosynthesis. The energy of the fuels we now burn (two-fifths as oil, one-third as natural gas, and one-fifth as coal) was in the form of solar radiation at an earlier time. It was absorbed by plants, reduced to petroleum, coal, and natural gas, and now some of it is being utilized as fuel. Our modern industrial economy is therefore built upon photosynthesis; on the products of ancient plants, which trapped the sunlight and produced the fossil fuels, we now exploit after a few hundred million years in subterranian storage.

Energy conversion by photosynthesis is unusually efficient. Under optimal laboratory conditions and with monochromatic red light, an efficiency above 30% has been demonstrated. That is appreciably higher than any other known direct conversion of electromagnetic radiation to chemical potential energy for any part of the visible spectrum. We should be impressed by this accomplishment which plant evolution perfected more than a billion years before any photochemist existed on earth to appreciate the achievement. Man's work aside, the biosphere does an enormous energy conversion job in which photosynthesis plays an integral part. There is a world total of about 400 billion tons of protoplasm and its organic products. The daily turnover has been estimated at about one per mil. In terms of tonnage, that equals the entire world's annual coal production every 4 days.

The efficiency with which the ancient plants made use of sunlight is not relevant to our exploitation of fossil fuels; we have used those fuels because they were available and cheap. But, if we cannot count on their continuing availability in sufficient quantity and at costs which will be reasonably competitive, we may want to take a fresh look at the possibility of greatly expanded use of the photosynthetic abilities of modern plants to provide us with a new and acceptable fuel source.

If we wish to harness through photosynthesis a fraction of the solar radiation which falls on the United States, we need to know how much is available, how efficiently it can be converted, and how and at what efficiency it can be transformed into the energy of an acceptable fuel. Then we may set some bounds for the scale and utility of such an enterprise. Under field conditions, there are many factors which make the efficiency of energy trapping by photosynthesis significantly less than optimal. Fortunately, we know a great deal about those aspects of the photosynthetic process which are relevant here.[3]

There are four principal causes for energy dissipation as heat instead of storage as chemical energy in the photosynthetic products. First, most of the sunlight is supplied in wavelengths not absorbed by chlorophyll or other photosynthetically active pigments (figure 1). Second, the energy conversion, being a quantized process is maximally efficient only with light of the longest useable wavelength; shorter wavelengths (larger quanta) perform the same function with essentially the same number of light quanta but with more energy waste (table 1). So, even in the photosynthetically active region of the solar spectrum the *average* conversion efficiency must fall short of the optimal. Third, although photosynthetic rate depends on the incident radiation intensity, in most cases the function is not linear except at rather low light intensities. If the rate is tested at higher and higher intensities of incident light, the successive increments diminish progressively and, usually at an intensity well below that of full sunlight, "saturation" occurs. Above the saturating light intensity, additional energy input is quantitatively wasted as heat. The fourth factor is temperature. The higher the temperature, the higher the light intensity before a point of diminishing returns is reached. However, there is an upper limit to what can be gained by elevating the temperature of photosynthesizing plant leaves which, like other biological systems, do not exhibit an infinite thermal tolerance. These main sources of energy wastage, along with others, account for the large differences in effectiveness with which different plant species or different kinds of plant communities trap solar energy in nature. The variation, under natural conditions, is very large and, in any case, the conversion efficiency is only a few percent.

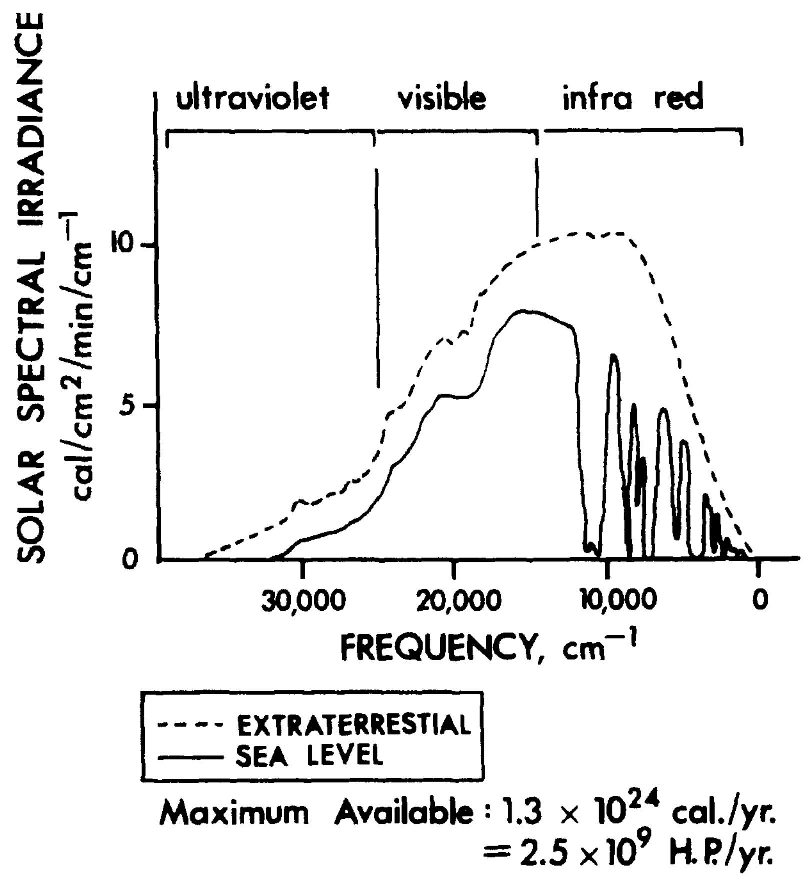

Figure 1. The Spectrum of Solar Energy

The solid curve encloses the energy input which reaches the earth's surface. Chlorophyll absorbs light for use in photosynthesis only in the visible portion of the spectrum.

Table 1. The Practical Upper Limit for Photosynthetic Efficiency

Efficiency defined:	$\frac{\text{Chemical potential energy stored}}{\text{Total solar energy reaching plant}}$
Equation:	$\frac{\Delta F \times \lambda_p}{r \times n \times N_o \times h \times c \times k}$
Identification of terms:	ΔF = free energy change in photosynthesis
	n = quantum requirement
	N_o = Avagadro's number
	h = Planck's constant
	c = speed of light
	k = dimensional constant, calories/erg
	r = fraction of input wavelengths which are photosynthetically active
	λ_p = wavelength equivalent to mean of photosynthetic action spectrum
Maximal efficiency attainable:	0.13

We have a good theoretical understanding of why some plants are more efficient than others in their photosynthetic performance (table 2). The differences are based on differences in pigmentation, on biochemical differences in pathways of carbon dioxide incorporation, on physiological properties, and even on the morphology of tissue regions in the plant leaf. For present purposes, we have available the results of numerous field studies of plant growth rates, of crop yields, and, over short intervals, of directly measured photosynthetic rates so that our estimates of photosynthetic effectiveness in trapping sunlight can be based largely on empirical measurements.[4-11] Although it is not yet certain which plant or plant community would be most suitable as a "fuel crop", it is encouraging to note that there are a number of contenders for that place of honor.

We should rid ourselves of some widely held misconceptions if we undertake to make a choice (table 3). Our economic and cultural emphasis on high-yielding crops which have a short growing season may lead us to ignore the slower growing species which may be storing energy over a much larger portion of the year. It is for this reason that forest land often shows greater annual productivity in terms of dry weight of accumulated organic compounds than does the genetically selected, fertilized, protected, and high-yielding farmland crop.[12] Moreover, there are water plants which now have no commercial value and may even be despised as troublesome weeds which exhibit especially high productivities so an imaginative exploration of the potential for impounding many large shallow ponds to grow vast acreages of lagoon weeds should not be dismissed as too fanciful.[13-18] The point here is that whether the fuel crop could be produced best by agriculture, silviculture, or mariculture[19] cannot yet be decided as each of the three appears to have an important potential.

Table 2. Energy Losses During Photosynthesis

The factors tabulated result in less than maximal efficiency of energy conversion by photosynthesis.

Ineffective wavelengths	55%
Crop coverage below 100%	5%
Reflection from water or plant surfaces	11% to 20%
Transmission (nonabsorption)	3%
Absorption by inactive pigments	4% to 8%
Fundamental limitation on quantum efficiency	71%
Rate limitation through CO_2 deficiency	10% to 20%
Rate limitation through light saturation	25%
Rate limitation due to mineral deficiency or drought	4%
Rate limitation due to nonoptimal temperature	5%
Respiratory and other metabolic destruction of photosynthate	10% to 50%
Destruction by diseases, grazing, etc.	5% to 50%
Losses in crop harvesting, transport, or storage	2%
Minimal overall losses compounded	94.4%

Table 3. Relative Productivities of Representative Crops and Plant Communities

Plant or Community	Metric tons per hectare per year
Desert scrub	0.7
Temperate angiosperm forest	11.2
Cottonwood stand	6.5 to 11.7
Temperate gymnosperm forest	12.6
Sugar beet	17.0
Tropical rain forest	23.8
Marsh	32.1
Maize	24.0 to 34.1
Rice	35.1
Sewage pond	45.0
Reedswamp	45.9
Pangola grass	50.4
Sugar cane	86.9
Water hyacinth	11.1 to 148.2

The organic compounds of a fuel crop probably would not be acceptable directly as fuel and they must be converted to a product which, preferably, could be used interchangeably with one of the fuels we hope to supplement. For this purpose, methane, the major constituent of natural gas, would be an excellent choice. The conversion of organic materials to methane occurs readily in nature in places where anaerobic conditions prevail. The emanation of marsh gas (methane) from swamps and from garbage and trash covered by land fill operations is a well-known phenomenon. The gas produced from treatment of domestic sewage has been used to fuel the treatment plant.[20] A methane plant was built on a 1000-animal pig farm in South Africa about 15 years ago and, over a period of years, a substantial profit accrued from the commercial value of the gas produced. An even larger saving resulted from reduction in the cost of handling pig manure.[21] Other examples might be cited where such energy recycling on a relatively small scale has demonstrated the feasibility and practicality of fermentative conversion of the energy of organic compounds into the energy of methane gas. However, those demonstrations do not tell us much about the efficiency of that microbiological processing and they give no basis for projecting what yield could be expected, if the process were maximized.

At the University of Pennsylvania, some research on these matters has been carried out under the sponsorship of the National Science Foundation. At least a beginning has been made on the task of optimizing the methane yield from bioreactors. Part of this research program has been carried out at the United Aircraft Research Laboratories. This dual effort in bioreactor technology has discovered some important operating parameters of the anaerobic digestion and fermentation which can produce methane in rather good yield.[22]

The initial step in converting the organic feed stock is a breakdown of more or less high-molecular-weight compounds into smaller products by hydrolysis. These include sugars, amino acids, and fatty acids along with many less abundant products. Some carbon dioxide also is evolved. The fermentations, catalyzed by different microorganisms, next transform the hydrolysates and generate mostly methane but also hydrogen, ammonia, and hydrogen sulfide. Overall the gas production has consisted of about two parts methane to one part carbon dioxide. In a single-stage lab-scale (28-liter) bioreactor operating at 37°C, a yield of 5.6 cu ft methane/lb dry weight organic matter has been demonstrated. In terms of energy, the conversion amounts to a little more than 50% (figure 2).

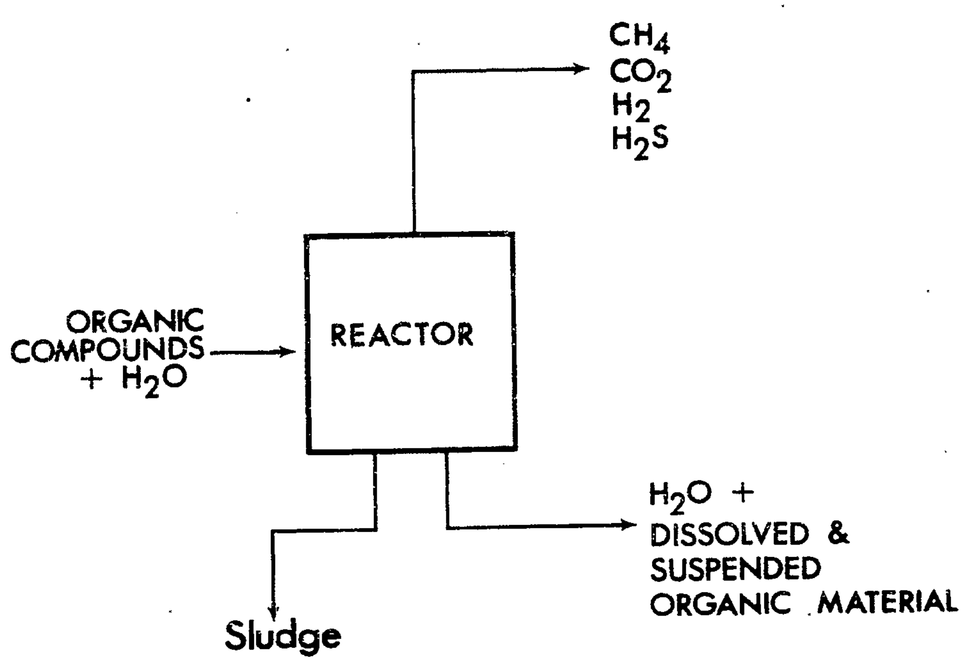

Figure 2. The Fermentative Production of Methane from a Mixture of Organic Compounds

By operating a reactor at a higher temperature, some increased yield might be anticipated through the selection of a thermophilic population of microorganisms which could exhibit a higher metabolic rate. So far experience has not borne out that expectation. At least up to 48°C, the thermophilic flora does about as well but not better than the mesophilic organisms at 37°C. This result is consistent with independent observations from another laboratory where the productivity was found to be even a little higher at 35°C than at 45°C.[23] Whether still higher temperatures or other reactor conditions might induce superior performance from thermophiles remains to be demonstrated.

One important condition, regulating population growth and therefore reactor performance, is acidity. In the digestion phase, the pH optimum occurs on the acid side whereas, during the subsequent fermentation of hydrolysates, the optimum is above pH 7. This implies that the overall conversion might be carried out advantageously in two physically separate reactors connected in tandem. When that was tested, the first reactor (digester) was operated at pH 6.0 and the gas produced was mostly carbon dioxide with some hydrogen. The second reactor (fermenter), which was fed by effluent from the first and was operated at pH 7.5, produced methane mixed with some carbon dioxide (figure 3). Overall the yield of the two-stage process was 8.4 cu ft of gas per lb of dry organic matter supplied to the first stage. The gas evolved from the second-stage (fermenter) was 80% methane. There may be advantages of two-stage reactor processing of organic materials to make methane, but that remains to be determined by further research. There are uncertainties in projecting yields from laboratory-size reactors to very large-scale operations. Nevertheless, the yield data available so far have been encouraging and they may be used cautiously to continue the examination of what might be feasible on a scale which could augment significantly our nation's fuel supplies.

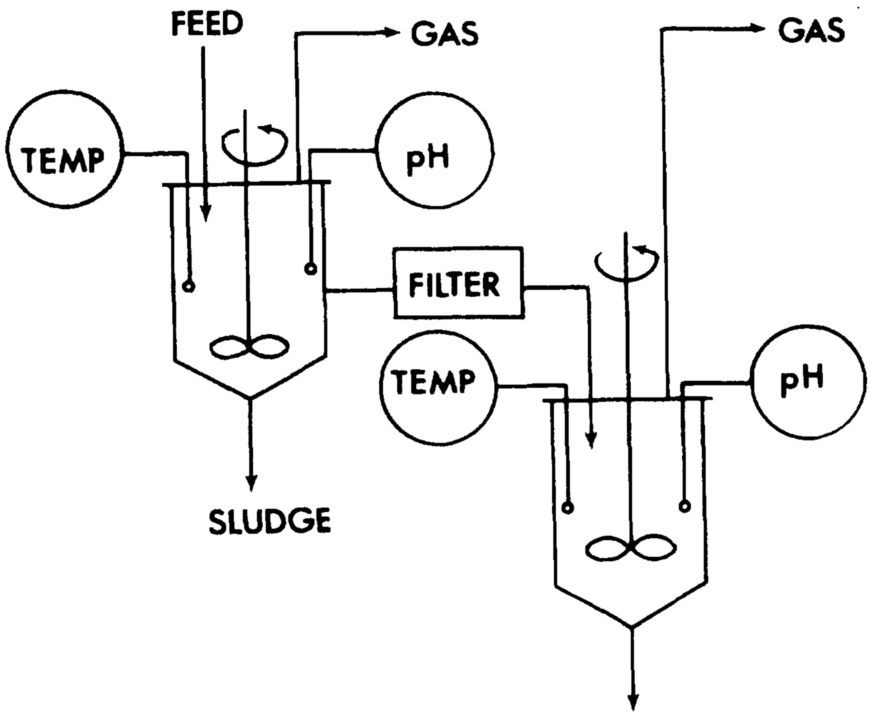

Figure 3. Schematic Diagram of Two-Stage Methane Production

In the first reactor, the feedstock is digested or hydrolyzed. The principal gas produced is CO_2. In the second stage, fermentation produces CH_4 at up to 80% purity.

Given the annual photosynthetic yield of a representative fuel crop (3%), a bioreactor conversion efficiency (60%), a combined estimate of the efficiency of harvesting, processing, fuel gas purification and compression (95%), the overall yield would be 1.7%. Some energy (for fertilizing, harvesting, etc.) would have to invested in crop production and this we estimate as 10% of the energy in the crop.[24] Our net yield estimate then becomes about 1.5% of the total solar energy reaching the crop area.

To appreciate the potential for practical application, let us take as a yardstick the United States natural gas consumption which in terms of fuel energy has been about 2×10^{16} Btu. Annual insolation over the United States averages about 1.5×10^{13} Btu per square mile (table 4). At a 1.5% conversion efficiency, 8.5×10^{4} square miles would be required to raise a fuel crop large enough to produce a supply of methane gas equivalent to our United States gas consumption yardstick. That amounts to about the combined areas of Alaska and Texas.

Table 4. Annual Insolation at Several United States Locations

Station	Btu per Square Mile per Year
Madison, Wisconsin	1.24×10^{13}
Tilton, Georgia	1.49×10^{13}
Hawaii	1.60×10^{13}
Davis, California	1.65×10^{13}
Puerto Rico	1.65×10^{13}
Imperial Valley, California	1.80×10^{13}

Of course, it should be possible to use as a feedstock for the bioreactors a substantial fraction of the organic wastes our society now produces. Since we now have to bear the burden of disposing of this material, it might acquire a negative cost if we were to divert and recycle it for fuel production. The amount of organic wastes which we produce has been estimated at 900 million tons of dry matter per year (table 5).[25] At a conversion ratio of 5 cu ft of methane per pound of dry matter and 10^3 Btu per cu ft, anaerobic fermentation could furnish us with about 9×10^{15} Btu annually in the form of methane. Thus, as much as 45% of our fuel gas requirements might be obtained from what we now consider garbage, if we were able to divert it all for that purpose. That goal clearly would be unattainable; an estimate that no more than 50% of the organic wastes could be recycled for methane production might be nearer the truth. Therefore, we could expect to increase our fuel gas supply by perhaps 20% or 25% from methane which would be derived from organic wastes. That projection, which I believe is conservative, is based on a calculation which includes some shaky estimates of United States waste productions and of the still-uncertain yields which might be attained through anaerobic fermentation. I also have assumed that the cost in energy input to a waste-processing operation would be offset by the savings in energy now expended for waste disposal.

In the short time available, I have described the essential reasons for optimism regarding the feasibility of opening up a new source of fuel based on harvesting the sun's energy through contemporaneous photosynthesis. It seems that the prospect is sound but that the potential is not known as accurately as we should like. Nevertheless, the concept is interesting and if large-scale operations should be undertaken there might accrue a number of advantages worth noting.

1. The fuel produced would be methane, the same material as natural gas. It could be purified at relatively low cost and could be introduced directly into existing pipelines.

2. Methane is a clean fuel whose combustion leaves no radioactive or toxic residue. The problems of environmental protection would not be exacerbated on its account.

Table 5. United States Production of Solid Organic Wastes

Source	Tons per year	Dry fraction	Organic fraction	Tons of dry organic matter per year
Urban	2.56×10^8	0.8	0.7	1.43×10^8
Industrial	1.10×10^8	.7	.7	5.4×10^7
Agricultural:				
Animal	1.56×10^9	.3	.95	4.4×10^8
Vegetable	5.52×10^8	.5	.95	2.62×10^8
Total				9.0×10^8

3. A logical initial step in the manufacture of methane fuel would be the utilization of our current output of organic wastes. It appears that this alone could furnish one-fifth or more of the amount of gas we now consume as fuel. Accordingly, by recycling wastes alone, we might augment the total annual United States energy resources by as much as 5%.

4. By recycling wastes as reactor feedstock, the growing problem of solid waste disposal would be lessened.

5. The use of recycled wastes could be effective on either small or large scale. It lends itself to decentralized operations in contrast with most other schemes for augmenting our energy supply.

6. Thermal pollution would not be increased in the full amount of increased fuel consumption since the process is essentially the recycling of contemporary solar-energy input.

7. The introduction of more carbon dioxide into the atmosphere would not occur to the full extent of the increased fuel use since that process would largely substitute fuel combustion for the respiration, decay, and burning which otherwise would account for the oxidation of carbon compounds generated by photosynthesis. This would at least tend to minimize whatever might be the slowly increasing hazard of a cataclysmic climatic change initiated by the "greenhouse effect."[26]

8. Allocation of large tracts for production of a fuel crop would not be unsightly and, from that standpoint, probably would not be resisted aggressively by local communities as are the more controversial oil refineries, deepwater ports, nuclear reactors, or strip-mining operations.

9. The production of a fuel crop specifically to feed the methane reactors could be based largely on existing technology and its potential would depend chiefly on the land (or water) area that we would be willing to allocate for growing the crop and for processing it into methane. An absurd limit would be the replacement of our entire energy consumption by methane from bioreactors. A total United States consumption level of about 7×10^{16} Btu per year might be met by a fuel crop grown on about 300,000 square miles – about half the area of the Gulf of Mexico. If we should consider it reasonable to allocate approximately 2% of our land area to production of a fuel crop to supplement the methane production from all of our organic wastes, we probably could generate fuel equal to the full amount of our annual natural gas supply.

There are some potential disadvantages which ought to temper any unwarranted enthusiasm for the exploitation of the biological processes that we have been considering for augmenting our fuel gas supplies.

1. Recycling organic wastes may not be an unmixed blessing for sanitary engineers, some of whom feel that the sludge which will remain after processing by methane producing bioreactors will be more difficult to handle and to dispose of than the original waste material. If that proves to be the case, recycling organic wastes may not reduce the current cost of waste disposal and even might increase it.

2. If we face up to the problem of allocating very large tracts of land for fuel crop production, we should not believe that we could easily use waste land of little value for such a large-scale effort. Either valuable agricultural land which may be in use now, or land with obvious productive potential would have to be allocated.

3. Since water would be an essential ingredient for fuel crop production, the use of desert areas for that purpose would entail irrigation projects of monumental dimensions. From that standpoint, our fuel crop production might encounter the same problem as will the coal gasification plants which are planned for the water-poor Southwestern United States. Like conversion of coal to fuel gas, the production of a high-yielding fuel crop will require vast amounts of water, a factor which can only be neglected where adequate rainfall is assured.

What are the prospects for such a development effort? At the moment I cannot feel optimistic. United States energy policy has made a heavy commitment to nuclear power generations here on earth rather than to exploiting nuclear reactions in the sun which is the source of solar radiant energy. For a number of reasons, which I cannot go into now, with each passing year I personally become more skeptical of that commitment. While there have been some research efforts to complete what I should term the initial phase, viz., to determine bioreactor operating parameters and to scale up pilot operations to a level appropriate for costing the methane fuel which could be madein this way, those projects no longer are receiving Federal support. Therefore, I cannot describe the national effort, even with respect to lab-scale research on this problem, as very ambitious. It certainly is less than adequate for a timely engineering evaluation of the potential gain to be realized from organic wastes-into-fuel processing on a large scale.

The second phase, viz., raising a fuel crop specifically to use in the methane-generating reactors thus to supplement the supply of organic wastes for this purpose, is not as urgent. It could be started after large-scale fermentative methane production from recycled wastes has been reduced to practice. That second phase would require careful preparation and planning because of the operating scale and the land allocation problems which would be involved. Nevertheless, raising a fuel crop even on rather large scale does not appear to offer any insolvable technological problems.

My personal view is that the methane fuel potential from massive recycling of organic wastes should be sought more aggressively by a modest increase in R&D effort. The feasibility seems so well established that we are not in doubt about whether it will work technically; the only uncertainty is the cost of the methane to be produced by fermentation. I believe the cost will surely be acceptable and to whatever extent we can supplement our fuel gas supplies, even should it amount to only a 20% increment, the gain will be significant. I further believe that raising a fuel crop specifically to provide bioreactor feedstock would be premature at this time. However, the future potential could be enormous and, compared with several other methods for augmentation of our fuel supplies which currently seem more popular, I think the photosynthesis-fermentation alternative has important advantages.

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ENZYMATIC HYDROLYSIS OF CELLULOSIC WASTES

by

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Cellulose is our most abundant organic material which can be used as fuel. The net world wide production of cellulose is estimated at 100 billion tons per year. This is approximately 150 pounds of cellulose per day for each and every one of the earth's 3.7 billion people. The energy to produce this vast quantity of cellulose comes from the sun and is fixed by photosynthesis as discussed by Dr. Brown. The energy from the sun, available over the United States alone, is between 4 and 5×10^{19} Btu per year.

This is approximately 600 times the annual energy consumption of the United States. Prior to 1900, our principal sources of energy were the wind, wood, water power, and coal. During this century, we have been relying very heavily on fossil fuels originally produced by photosynthesis. Our energy consumption in the United States has been estimated at 7 to 8×10^{16} Btu per year. This total energy is obtained primarily from oil (43%), gas (35%), and coal (19%).[1] Comparison of the annual energy consumption in 1873 (4.2×10^{15} Btu per year), with that of today, shows that our current demand is approximately 17 to 20 times more than what we used in 1873. This phenomenal growth in energy demand will be difficult, if not impossible, to support with our current fuel reserves regardless of processing capabilities.

By the year 2000, undoubtedly nuclear power may be a major source of energy; however, to achieve the ultimate goal of independence, we will have to harness effectively and economically the inexhaustible energy of the sun.

Since cellulose is the only organic material that is annually replenishable in very large quantities, we should explore many ways to utilize it as a source of energy, food, or chemicals. The utilization of this resource is greatly simplified if cellulose is first hydrolyzed to its *monomer* glucose as shown in figure 1. Once we have formed the glucose, it can be used as a food consumable by man and animals, it can be converted to chemical materials, it can be converted microbially into single cell proteins, and it can be fermented to clean burning fuel (ethanol), solvents (acetone), and other chemicals, etc. It is estimated that from one ton of wastepaper we can produce one-half ton of glucose which can be fermented to produce 68 gallons of ethanol. Several studies, conducted in the past several years to determine the suitability of blending methanol and ethanol with gasoline for use in internal combustion engines, have shown that this can be done easily with only minor modifications if any to present engines. Moreover, it has been found that engines burning these blended fuels have fewer problems with exhaust emission.[2,3]

The simplicity of hydrolyzing cellulose to glucose and converting the latter to chemical feedstocks to conserve petroleum, which is now used to make petrochemicals or fermenting the glucose to ethanol that can be easily blended with gasoline to power automobiles and other internal combustion engines, could alleviate our immediate energy crisis.

The shortage of fuel that has been estimated at 2.5 to 5.0 million barrels per day could be easily met by the daily hydrolysis of 1.5 to 3.0 million tons of waste cellulose present in municipal trash and agricultural wastes. Conversion of cellulose to glucose can be done by either acid hydrolysis or by enzymatic processes.[4-14] There are various advantages in the use of enzymes to hydrolyze cellulose instead of acid. When using acid, expensive corrosion proof equipment is required. Waste cellulose invariably contains impurities which will react with the acid producing many unwanted byproducts and reversion compounds in the digest. The enzyme, on the other hand, is specific for cellulose so that the glucose formed is fairly pure and constant in composition.

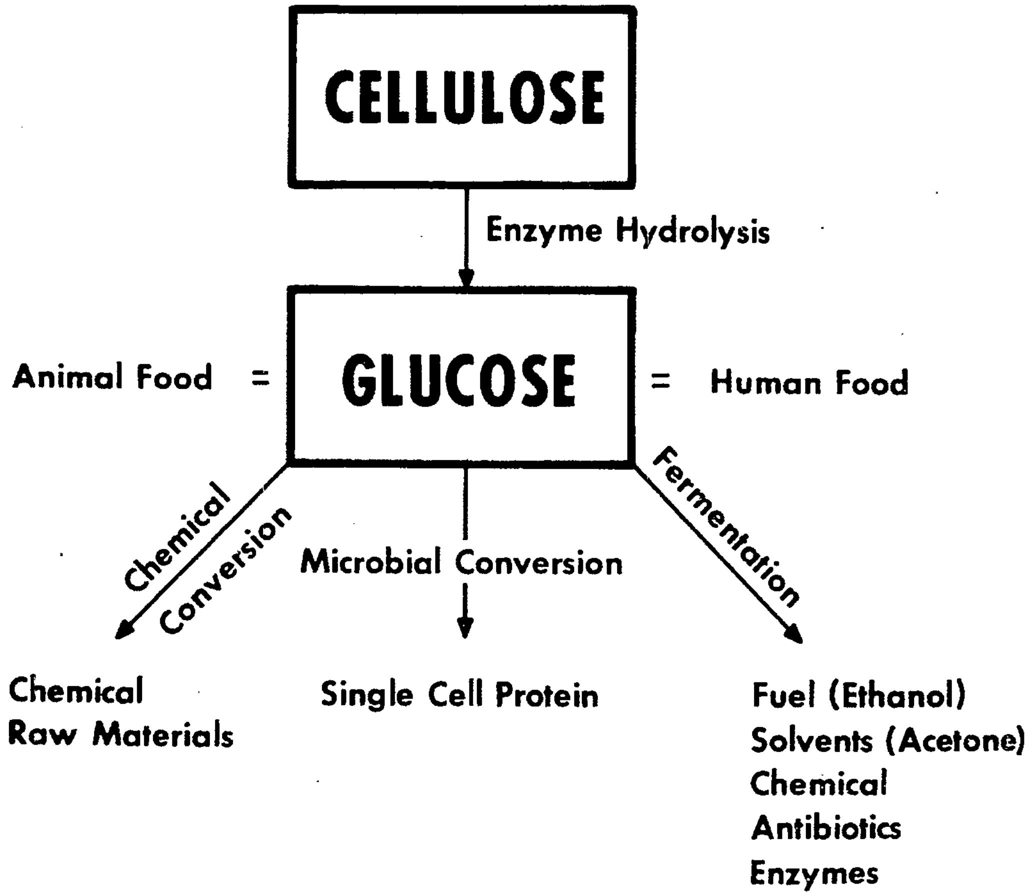

Figure 1. Utilization of Cellulose

We, at the US Army Natick Laboratories, are developing an enzymatic process, which is based on the use of the cellulase enzyme derived from a mutant of the fungus *Trichoderma viride* isolated and developed at the Natick Laboratories. A schematic diagram of such a process is shown in figure 2. Our first step is the production of the enzyme. This we accomplish by growing the fungus *Trichoderma viride* in a culture medium containing shredded cellulose and various other nutrients. After 5 to 10 days, the fungus culture is filtered and the solids discarded. The clear straw colored filtrate is the enzyme solution that is used in the saccharification reactor.

Prior to its introduction into the reactor, the enzyme broth is assayed for cellulase and its acidity adjusted to a pH of 4.8 by addition of a citrate buffer. Milled cellulose is then introduced into the enzyme solution and allowed to react with the cellulase to produce glucose sugar. You will note that saccharification takes place at atmospheric pressure and low temperature (50°C). The unreacted cellulose and enzyme is recycled back into the reactor, and the crude glucose syrup is filtered for use in chemical, microbial, and/or fermentation processes to produce chemical feedstocks, single cell proteins, fuels, solvents, etc.

The key to this process is the production of high quality cellulase from *Trichoderma viride*. During the past 20 years, extensive studies of this fungus and its enzyme have been made at the Natick Laboratories in connection with the program on prevention of deterioration of cellulosic materials. For this process, today we are interested in accelerating deterioration. To date, we have defined the conditions needed to produce the enzyme in quantity. We have also developed mutant strains that produce two to four times as much cellulase as the wild strain. In this area, we feel that we have yet to reach the upper limit.

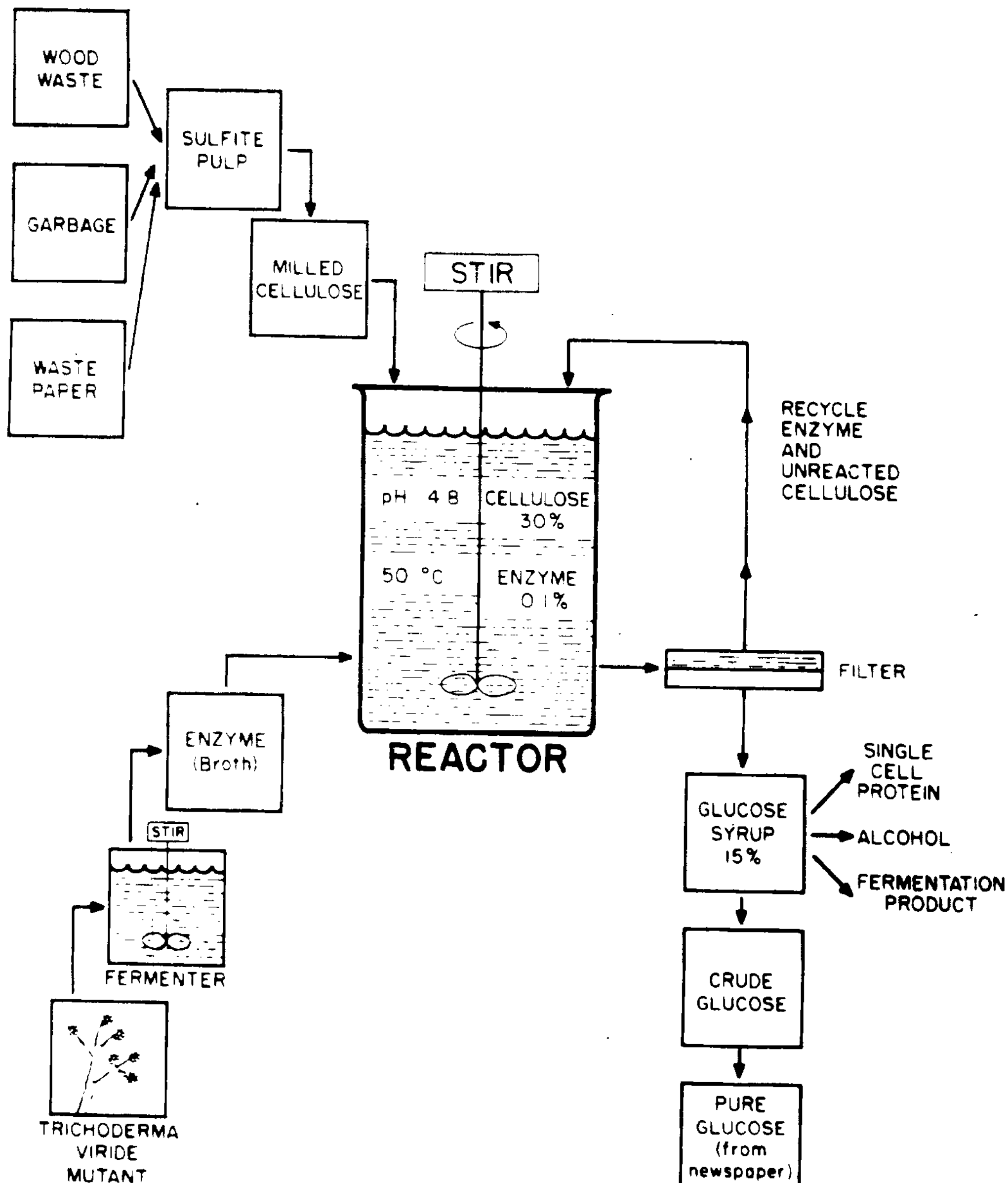

Figure 2. Conversion of Waste Paper Products to Glucose Sugar

Another important variable to be optimized is the preparation of the substrate. The insolubility and crystallinity of pure cellulose and the presence of lignin in waste cellulose make it a most resistant substrate. The most satisfactory pretreatment we have found is ball milling. This reduces the crystallinity and particle size of the cellulose and increases its bulk density. Consequently more cellulose is available for saccharification in the reactor. Figure 3 shows the hydrolysis of a number of pure and waste celluloses by the culture filtrate of *Trichoderma viride*. Saccharification is slow for crystalline cellulose such as cotton or untreated rice hulls or bagasse. Pot milling greatly increases their reactivity. Shredded or milled papers make good substrates. The Black-Clawson fiber fraction, from the hydropulping separation of municipal trash, is an excellent material especially after milling. The same is true for the cellulose fraction separated by dry air classification of municipal trash by the Bureau of Mines' process. Since these waste materials contain impurities, hydrolysis is limited to the cellulosic fraction of the substrate.

	% SACCHARIFICATION			
Substrate	**1 hr**	**4 hr**	**24 hr**	**48 hr**
PURE CELLULOSE				
Cotton – Fibrous	1	2	6	10
Cotton – Pot Milled	14	26	49	55
Cellulose Pulp SW40	5	13	26	37
Milled Pulp Sweco 270	23	44	74	92
WASTE CELLULOSE				
Bagasse	1	3	6	6
Bagasse – Pot Milled	14	29	42	48
Corrugated Fibreboard Mighty Mac	11	27	43	55
Corrugated Fibreboard Pot Milled	17	38	66	78
Black Clawson Fibers	5	11	32	36
Black Clawson Pot Milled	13	28	53	56
Bureau of Mines Cellulose	7	16	25	30
Bureau of Mines Pot Milled	13	31	43	57

Figure 3. Hydrolysis of Cellulose by *Trichoderma viride* Cellulase

It was stated earlier that pretreatment of the substrate is an important variable. This variable will affect not only the degree of saccharification but also the economics of the process. Using newspaper as the base substrate, various techniques were tried and the results are shown in figure 4. It should be noted from these studies that pot milling and ball milling proved best.

Newspaper (Boston Globe)	% SACCHARIFICATION 1 hr	4 hr	24 hr	48 hr
Mighty Mac – Mulcher	10	24	31	42
Jay Bee – Paper Shredder	6	12	24	27
Pot Mill	18	49	65	70
Sweco Mill	16	32	48	56
Granulator–Comminutor	6	14	24	26
Fitzpatrick (Hammer Mill)	10	16	25	28
Majac (Jet Pulverizer)	11	15	26	29
Gaulin (Colloid Mill)	9	17	27	31
Soaked in Water	7	13	24	28
Boiled in Water	4	9	21	26
Treated 2% NaOH	8	14	28	35
Viscose	15	30	44	51
Cuprammonium	18	35	52	58

Figure 4. Pretreatment of Newspaper

Because of its specificity, the cellulase enzyme reacts solely with the cellulose and is not affected by other impurities present in the reactor. Figure 5 shows the results achieved with milled newspaper digested in a stirred tank reactor.* Glucose syrups of 2% to 10% concentrations were realized. The ink, lignin, and other impurities present did not cause any problems. The residue, after hydrolysis, was a black sticky material that dried to a hard unwettable cake. This material is chiefly lignin which can be burned as a fuel or used as a source of chemicals.

Having proved that this process is technically feasible, our next step is an intensive pilot plant study to optimize all variables and obtain the engineering and economic data needed for the design of a demonstration plant.

In collaboration with Fermentation Design, Inc., of Bethlehem, Pennsylvania, we have engineered a highly instrumented pilot plant consisting of such equipment as:

1. Fermenters
2. Enzyme reactors

*Brandt, D., Hontz, L., and Mandels, M. Engineering Aspects of the Enzymatic Conversion of Waste Cellulose to Glucose. AIChE Symposium Series. In Press.

Mandels, M., Hontz, L., and Brandt, D. 1974. Enzymatic Hydrolysis of Waste Cellulose. In preparation.

Enzyme Protein mg/ml	Newspaper %	Temp C	Glucose 1 hr %	Glucose 4 hr %	Glucose 24 hr %	Glucose 48 hr %	SACCHARIFICATION %
0.7	5	50	1.0	2.0	2.8	–	50
0.7	5	50	1.0	2.0	2.3	–	42
1.0	10	50	2.1	3.1	5.5	7.3	66
1.6	10	45	2.0	3.6	5.4	6.5	59
1.6	10	50	2.3	4.2	6.4	6.3	57
0.8	15	45	1.5	2.8	5.3	7.7	46
0.8	15	50	0.8	2.8	6.1	6.3	38
1.8	15	50	3.2	6.0	8.6	10.0	60

Reactor Volume 1 Liter Stirred 60 RPM pH 4.8

Figure 5. Hydrolysis of Milled Newspaper in Stirred Reactors

3. Holding tanks and auxiliary vessels

4. Instrumentation modules

5. Substrate handling and preparation equipment

6. Enzyme recovery and concentration equipment

The design and construction is such that the most sophisiticated fermentation techniques including batch, continuous, and semicontinuous processes can be studied.

Because of the sophistication of the monitoring and control instrumentation, both the fermentation and the enzyme hydrolysis will be continuously monitored and controlled in order to optimize the output of the individual processes. Figure 6 shows the 250-liter biological reactor that will be used to study the cellulose hydrolysis. Figures 7 and 8 show the 400-liter fermenter with its 30-liter seed fermenter that will be used to produce the cellulase enzyme from the *Trichoderma viride* fermentation. Figure 9 shows the instrumentation cabinets for the fermenter and enzyme reactor which contain modules for control or analysis of temperature, pressure, agitation speed, pH, sparging, dissolved oxygen, vessel weight, liquid level, and exit gas.

Figure 10 shows the simplified schematic of the process. The initial capacity of this pilot plant is the processing of 1000 pounds of cellulose per month. This equipment is now being installed at Natick and will be operational by June. Our projected demonstration plant is to handle 200,000 pounds per month.

Because of the significant potential contribution this process can make to Project Independence, it has been brought to the attention of the National Science Foundation, the Atomic Energy Commission, and the Federal Energy Office.

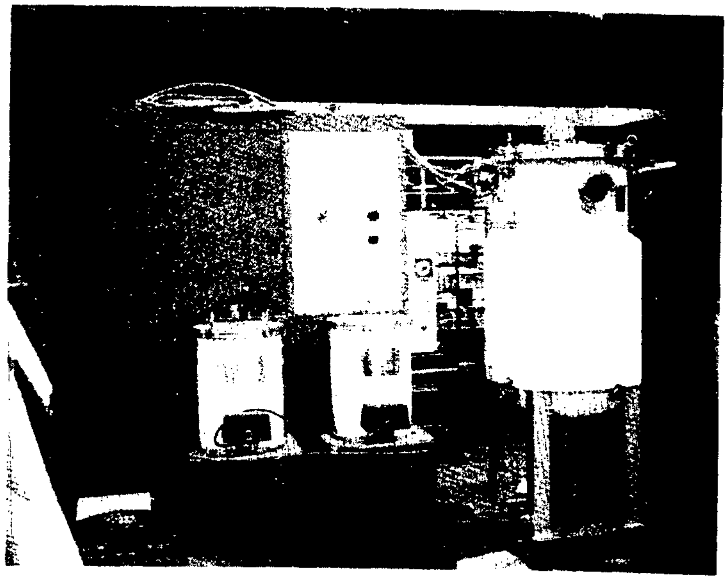

Figure 6. Biological Reactor, 250-Liter

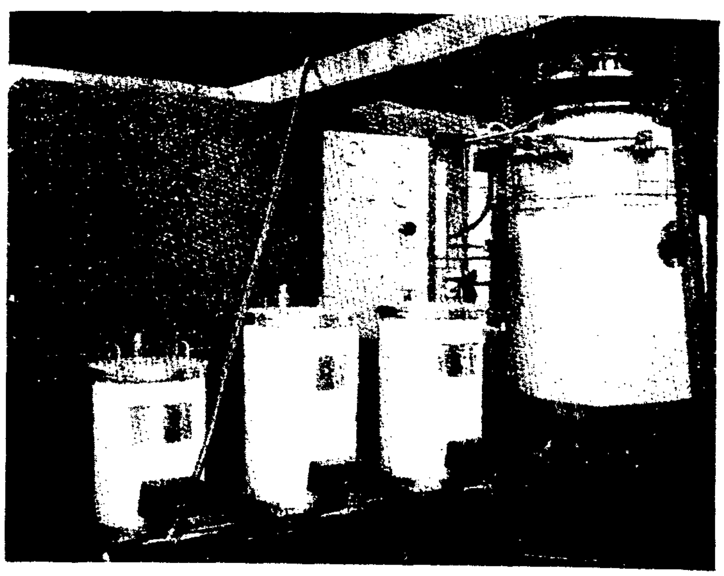

Figure 7. Fermenter, 400-Liter

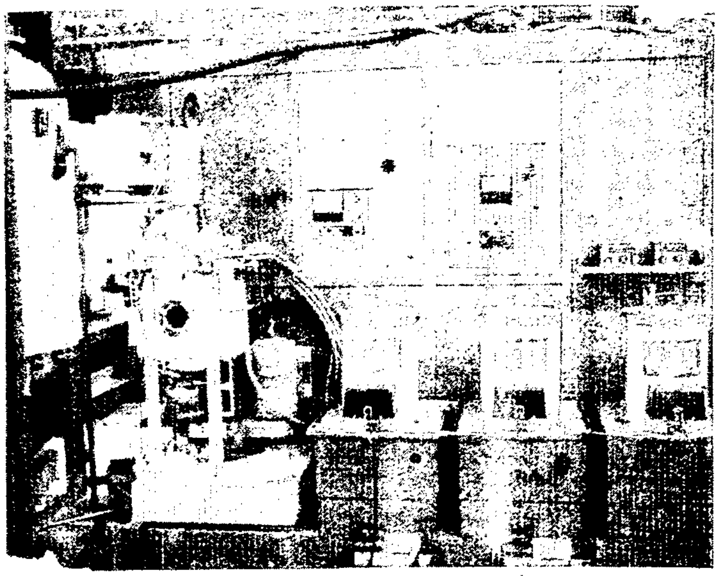

Figure 8. Fermenter, 400-Liter with 30-Liter Seed Fermenter

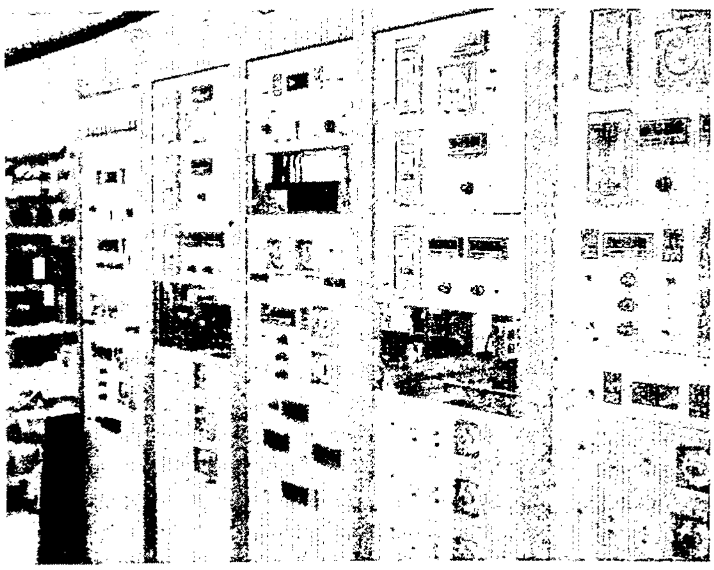

Figure 9. Instrumentation Cabinets for Fermenter and Enzyme Reactor

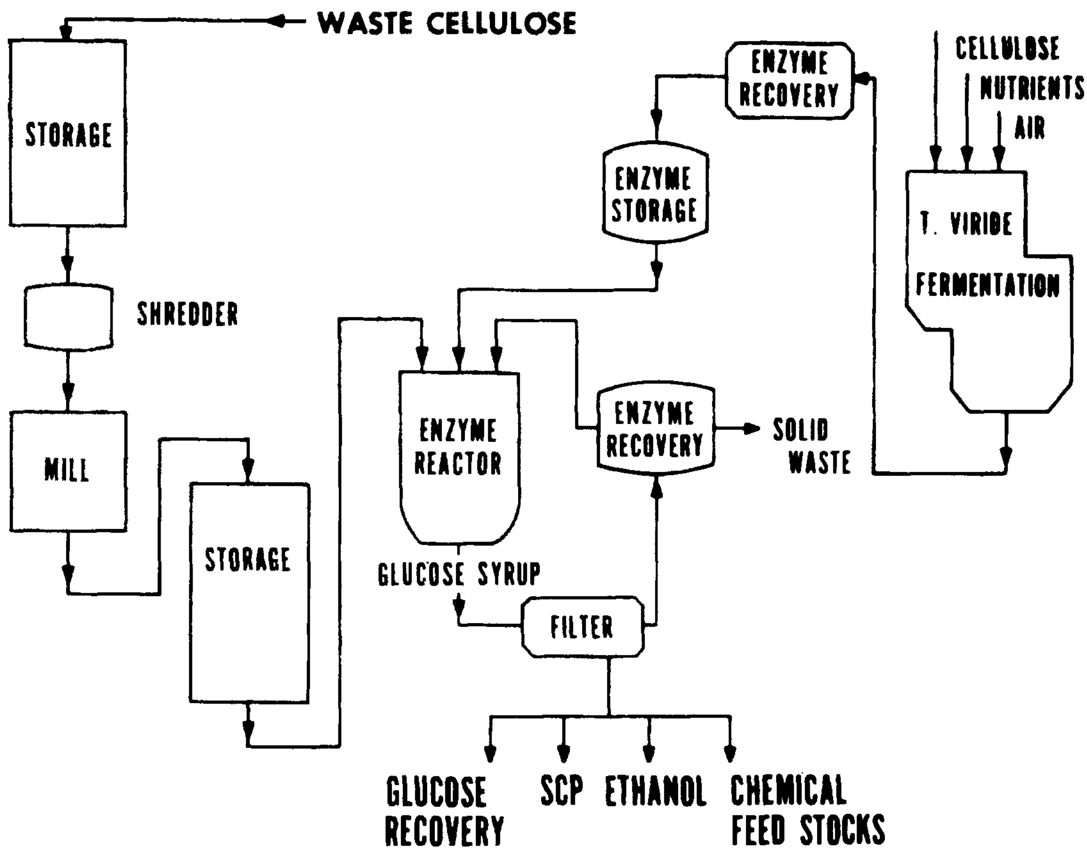

Figure 10. Enzymatic Conversion of Waste Cellulose

In conclusion, we at Natick are convinced that:

1. The vast quantity of cellulose that is replenished annually should be exploited as a source of energy, food, and chemical feedstock.

2. The enzymatic hydrolysis of such energy-rich material as cellulose to glucose is technically feasible and practically achievable on a very large scale by 1980.

3. The use of ethanol-gasoline fuel blends to power automobiles and other internal combustion engines should be encouraged in order to extend our petroleum reserves.

4. The exploitation of our fossil fuel reserves be it coal, oil shale, or otherwise, may satisfy our energy demands for the next 5 to 10 decades. However, what energy source can we explore at that time?

5. We believe that the ultimate long-range solution to the world's energy problem is the development of practical and economical processes capable of harnessing the inexhaustible energy of the sun.

We at Natick Laboratories look forward with great expectation and confidence to the opportunity of contributing to the effort that will make Project Independence a reality.

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COAL LIQUEFACTION AND GASIFICATION – A BRIEF OVERVIEW OF A COMING INDUSTRY

by

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INTRODUCTION

The development of technology to allow the most economic conversion of coal to gaseous and liquid fuels is a necessity if the United States is to reach its goal of achieving energy self-sufficiency. Therefore, hundreds of millions of dollars are being spent both by government and industry to insure the development and demonstration of this technology as quickly as possible with the urgency of this task intensified by the current petroleum and natural gas shortages.

This paper therefore describes what types of technology will arise from these current R&D efforts from which will come the establishment of a major synthetic fuels industry in the United States.

Why a Synthetic Fuel Industry?

For a long time the United States has enjoyed an abundance of cheap, clean, convenient fuels; namely, natural gas and petroleum and its derived products. The combination of relative low cost, convenience, and availability of these energy forms caused them to be consumed at a higher rate than coal which is our most abundant source of energy. Unfortunately, additions to United States reserves of both natural gas and petroleum have not kept pace with the increasing consumption of these fuels. The reserves of natural gas and petroleum were further reduced by the establishment of clean air laws which caused utilities to switch from sulfur-containing coals to these clean-burning fuels. In addition, increases in both population and per capita energy consumption accelerated the decline in domestic reserves of oil and gas until domestic demand could no longer be met by domestic production and petroleum imports were increased to supply the shortfall.*

Continuation along this path would be extremely difficult, even if there were no political problems, because it would create an overwhelming balance of payments deficit. Thus, the following factors establish the necessity for a United States synthetic fuels industry.

1. Coal supplies sufficient to last at least a couple of hundred years.
2. Lack of sufficient domestic supplies of petroleum and natural gas.
3. A society geared to the consumption of liquid and gaseous fuels rather than coal.
4. Economic and political barriers to satisfying our demands by importing petroleum and natural gas.
5. Environmental constraints against using coal directly.

*For example, in 1972, petroleum supplied about 46% of all domestic energy requirements followed by natural gas, 32%; bituminous coal, 17%; hydropower, 4%; nuclear, 0.8%; and anthracite, 0.2%. Energy produced by imported fuels accounted for 12.5% of the total, and this represented an increase of 24.5% over 1971.

There is also a resources conservation and economic argument for converting coal to synthetic gas rather than burning the coal for the generation of electricity because the investment cost for a synthetic pipeline gas plant is about equal to that for a powerplant having the same coal rate. In addition, the thermal efficiency of the pipeline gas plant is higher (70% versus 40%) than that of the power plant, the transmission costs are lower for moving pipeline gas than for electricity and, for many domestic uses, the final utilization efficiency of gas is higher than that of electricity (heating and cooking, for example).

COAL LIQUEFACTION

Hydrogenation

Coal liquefaction is carried out by adding hydrogen to coal to convert the coal to a liquid product which can be transported, stored, and utilized more easily than the original coal. In addition, since ash and sulfur are virtually eliminated during the liquefaction process, the liquid product can be used as a power plant fuel, thus freeing for the domestic and industrial market petroleum-derived fuel oils and natural gas currently being burned for the production of electric power. Power plants will probably constitute the largest consumers of coal-derived liquids from the pioneer liquid fuel plants. Other important uses of the liquid products will be for motor fuel* and aromatic chemicals.

Before discussing specific processes for converting coal to liquid products, it is helpful to examine a general flowsheet that illustrates the major unit operations in a coal liquefaction plant. A generic flowsheet, illustrating the major processing steps, is shown in figure 1.

The plant consists of a coal preparation step where run-of-mine coal is crushed and ground to a size consistency somewhat finer than table salt and, if there is much slate or shale in the coal, the preparation step may also include coal washing.

After preparation, the coal is mixed with a portion of the product oil to form a slurry containing usually 40% coal which is mixed with hydrogen and pumped into a reactor or reactors where sufficient residence time is allowed for hydrogenation to occur. This step can be carried out with or without a catalyst. The use of a catalyst allows more hydrogenation and a higher degree of sulfur removal to occur. Without a catalyst, the product will contain more sulfur and is only liquefied to an extent to allow solids separation to occur. The step of solids separation allows the sulfur occurring in the ash to be removed from the combustible portion of the coal. The product of the noncatalytic process is solid at room temperature and differs from the original coal only in being ash free and having a lower sulfur content. The primary market for this product is the utility industry.

After hydrogenation, the ash, unreacted coal, and heavier asphaltenic products are separated from the oil by liquid cyclones, filters, and/or centrifuges. Part of the oil stream is then recycled for slurry preparation with the remainder being used for product. The ash, unreacted coal, together with the entrapped oil and asphaltenic material are then fed to a coker where the lighter oils are driven off and sold as additional product, while the high ash content coke is used for the production of hydrogen by gasification which is described in the next section.

Liquefaction Processes Now Under Development

Processes at various stages of development that produce liquid fuels by hydrogenation include the following catalytic processes.

Synthoil Process – United States Bureau of Mines. This process employs a Co-Mo catalyst in a packed bed operated at pressures from 2000 to 4000 psig and at temperatures in the neighborhood of 426°C. Turbulent flow of slurry and hydrogen through the catalyst bed prevents plugging from occurring.

*Hydrogenation of coal to produce oil, which was then converted to gasoline, was carried out by the Germans during World War II and provided a significant fraction of the fuel for their war effort (36%).

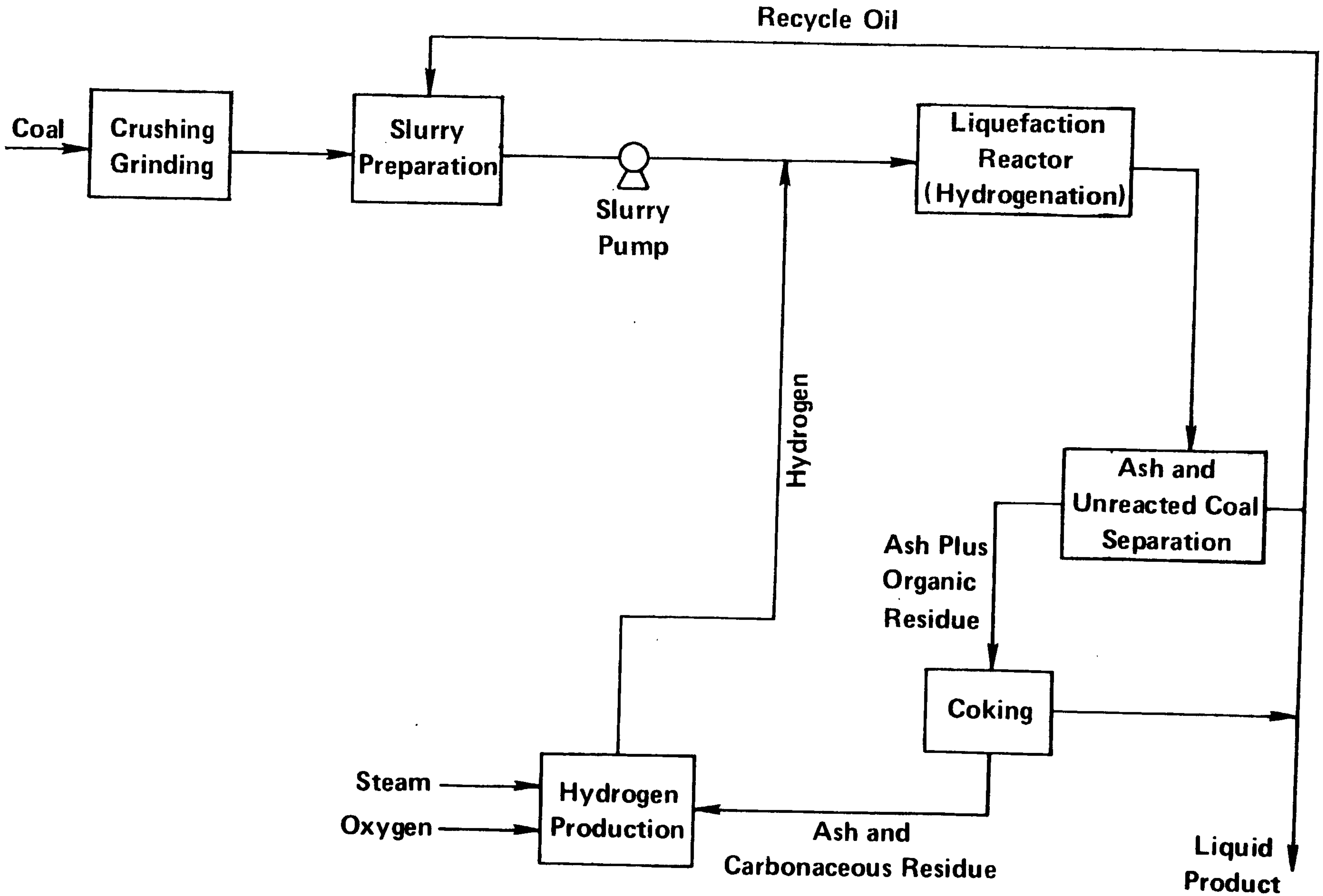

Figure 1. Simplified Flowsheet – Coal Liquefaction by Hydrogenation

H-Coal Process – Hydrocarbon Research. This process employs a fluidized catalyst bed instead of a packed bed and is patterned after a similar commercial oil hydrodesulfurization process called H-Oil.

Consol Synthetic Fuel (CSF) Process – CONSOL Coal Company (Division of Continental Oil). This process is conceptually different than the above two processes in that it hydrogenates the coal using hydrogen, contained in a hydroaromatic liquid, called a hydrogen donor solvent rather than by gaseous hydrogen. After this mild hydrogenation step, the solids are separated from the liquefied coal and the hydrogen donor solvent is regenerated by hydrogenation with gaseous hydrogen in a separate vessel in which a fluidized catalyst is used.

Zinc Chloride Process – CONSOL Coal Company. This process uses molten zinc chloride as a catalyst which is mixed with the coal and fed together through a hydrogenation reactor. In this fashion, a high yield of gasoline can be obtained in a single step. However, recovery of the zinc chloride is difficult and corrosion is a problem.

Bergius Process. This is a German development used during World War II to produce gasoline. This process uses a small amount (about 1%) of a finely divided catalyst (tin oxalate) that is intimately mixed with the coal paste and passed through the reactors. Use of catalyst in low concentrations allowed the catalyst to be rejected with the ash. Since gasoline was the desired end product, higher pressures (10,000 psig) were used than are considered practical in currently-developing United States technology.

PAMCO Process – Pittsburgh and Midway Coal Company (Division of Gulf Oil Company). In this process, the hydrogenation is done without a catalyst and, therefore, the amount of hydrogenation is lower than for other processes. The intent is simply to induce enough hydrogenation to liquefy the coal so that the ash may be removed. Removal of the ash, for many coals, allows a substantial reduction in their sulfur content. The resulting product is in the form of small solid beads at room temperature which are intended for boiler fuel.

State of the Art in Liquefaction

The processes described above have performed well in smaller scale studies and are, therefore, scheduled for further evaluation in pilot plants. The major difficulties in piloting these processes will be the lack of components and equipment available for coal liquefaction duty. This lack of equipment prevented the satisfactory operation of an earlier version of the CONSOL process which was intended to produce gasoline from coal. Therefore, plans are being made to accelerate the development of needed equipment and components.

A perspective of the scaling up that must be done to go from where we are now to a commercial plant may be gotten by examining the table which shows the approximate capacities of plants that have been operated in this country compared to the size projected for future commercial liquefaction plants.

This table indicates what I consider to be two major points. The first is that the plants we contemplate building are much larger than the plants operated commercially by the Germans during the Second World War, and the second is that the specialized level of experience and expertise, required to design liquefaction components and equipment, has declined with time. That this is true is evident from the United States experience at Union Carbide and the Bureau of Mines at Louisiana, Missouri, whose success is to a large extent attributable to the direct transfer of German design know-how and the availability of German personnel with direct operating experience. The next large-scale attempt made at Cresap, West Virginia, during the late 1960's, was plagued by the lack of suitable equipment to an extent that prevented the plant from ever being fully operational.

Thus, the introduction of a synthetic liquid fuels industry will first require the development of equipment that will allow the processes currently under development to be exploited on a scale never before attempted.

Table. Capacity of "Larger" Scale Liquefaction Plants – Past and Future

Plant description	Time operational	Comments	Capacity, bbls/day
Commercial coal Liquefaction plant Specific process not yet fixed	Early 1980's		50,000 to 100,000
Consol Project gasoline	1967-1970	Never fully operational because of equipment problems	70
Union Carbide Process	Late 1940's Early 1950's	Information scarce, but increased petroleum and natural gas availability made it uneconomical	9,000
USBM, Louisiana; Missouri Bergius Process	Early 1950's	Many operational problems not satisfactorily solved, but plant operated well enough to establish design data	200

COAL GASIFICATION

Converting coal to a gaseous fuel is required to satisfy two energy needs. One of these needs is for pipeline gas which can be used to supplement dwindling supplies of natural gas. The other is for a low-Btu gas which would be used on or close to the gasification site. Probably the most critical of these is the need for supplementary pipeline gas that has the heating value of, and is interchangeable with, natural gas. Current demand for this convenient cleanly burning fuel is so great that, in most areas of the country, there is a gap between supply and demand that is growing worse as time passes. Economic projections, based on existing technology (the Lurgi Process), to convert coal to pipeline gas indicate that pipeline gas can be produced as cheaply from coal as from naphtha (which must be imported and therefore has the same supply uncertainties as petroleum). Developing technologies for converting coal to pipeline gas offer an additional economic incentive as well as being more applicable to allowing the use of coal fines which arise from modern mining practices. Potential economic and operational advantages that these developing processes have over the Lurgi Process make their development to the demonstration plant scale a matter of prime national importance.

The development level of technology for converting coal to a synthetic natural gas (SNG) varies from bench-scale to commercially available. As with any other technology undergoing development, new process schemes are born on a regular basis while others die because they are either economically, technically, or operationally unsound.

Therefore, rather than describing all the potential candidates for converting coal to pipeline gas, only processes currently funded for pilot plant testing will be described.

Before describing individual processes, it will simplify things to examine a rather generalized and simplified flow sheet showing the major unit operations common to plants producing pipeline gas from coal. Such a flow diagram is shown in figure 2.

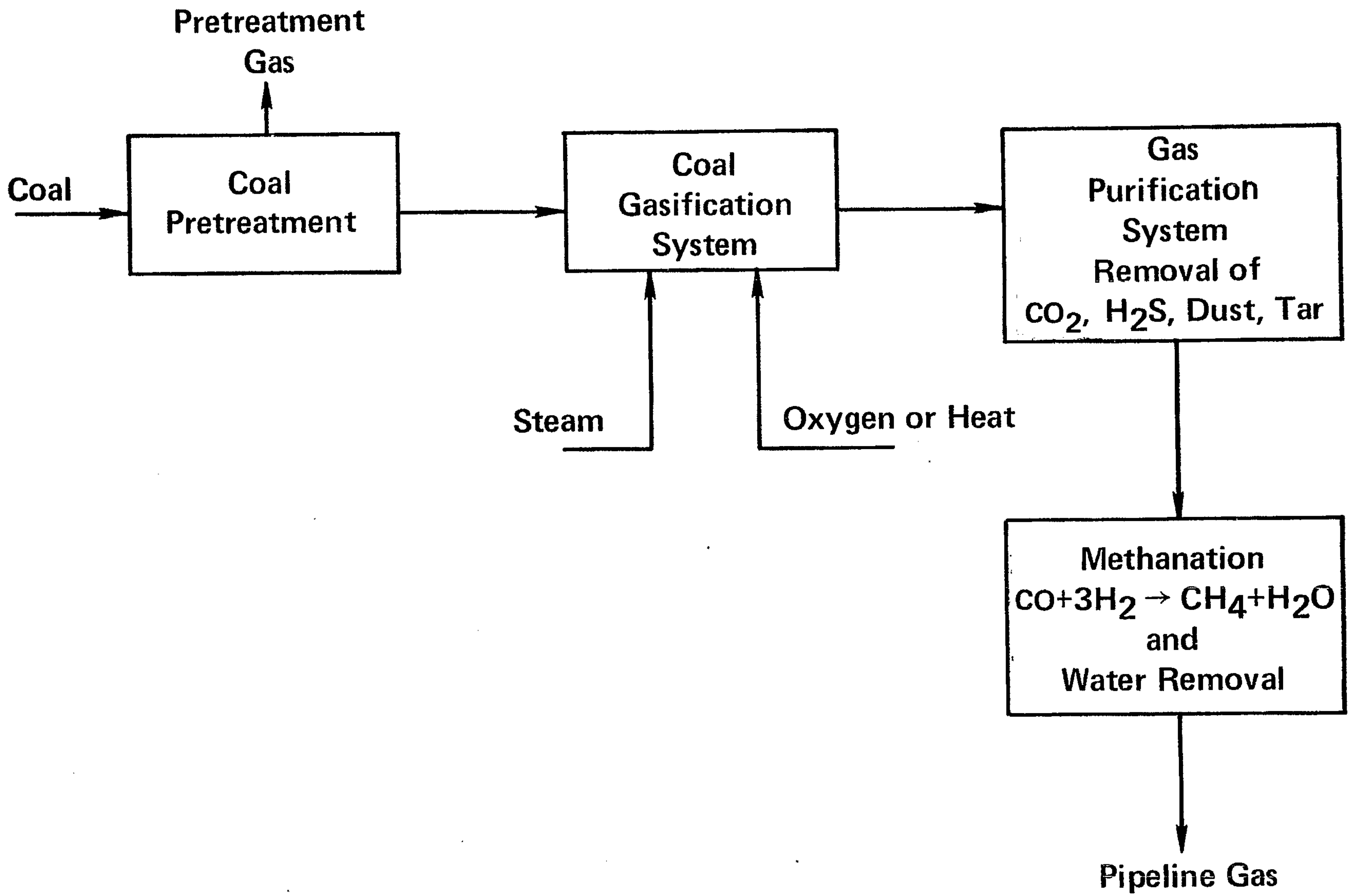

Figure 2. Simplified Flow Diagram for Producing Pipeline Gas from Coal

Ordinarily, if an Eastern coal is used, it must be pretreated before it is gasified to prevent agglomeration from occurring which would cause plugging and shutdown of the gasification reaction system. Pretreatment is simply the partial oxidation of the coal to oxidize the volatile constituents of the coal which would otherwise cause it to soften, swell, and stick. This removal of volatile matter is economically and technically undesirable because; its removal reduces the yield of methane per pound of coal and increases the hydrogen required to produce a unit of methane.

At this point it pays to examine the gasification step in greater detail because it is in this step that the various processes differ from each other. Basically, the so-called gasification step can be considered to consist of two separate steps. The first is the production of synthesis gas by the reaction of carbon in the coal with steam shown by the chemical equation,

$$C + H_2O \rightarrow CO + H_2 \quad , \tag{1}$$

and the mixture of CO and H_2 from this reaction is called synthesis gas. This name comes from the fact that the H_2/CO mixture can be used for the synthesis of many chemicals.*

The reaction indicated by chemical equation (1) requires a high temperature (in the neighborhood of 1800°F) and also absorbs much heat. Therefore, the purpose of the oxygen is to burn part of the carbon to provide this heat. The oxygen requirement for the gasification reaction is one of the prime contributors to the cost of producing pipeline gas. For this reason, one of the goals of the emerging gasification technologies is to reduce oxygen consumption.

As is mentioned above, the step called gasification consists of two steps: (1) the generation of synthesis gas, just described, and (2) the reaction of the hydrogen in the synthesis gas with coal to produce methane which is the desired end product of the process. This reaction is analogous to that described by the chemical equation for producing methane from carbon,

$$C + 2H_2 \rightarrow CH_4 \quad . \tag{2}$$

Also, additional methane, as well as some tars, are produced by the devolatilization of the coal with the hot synthesis gas. The means of producing methane by direct reaction of carbon in coal with hydrogen is called hydrogasification and, because it is a direct reaction and is itself exothermic, it reduces the oxygen and coal requirements needed to produce a unit of methane. Therefore, from an economic point of view, it is desirable to produce as much methane as possible by hydrogasification.

The gases exiting the coal gasification system consist of CO, H_2, CH_4, CO_2, H_2S, H_2O, tars, and dust. The gas purification system removes tars and dust as well as undesirable gaseous constituents such as CO_2 and H_2S. It also adjusts the H_2 to CO ratio to allow additional methane to be made by a process known as methanation and it is this step, together with hydrogasification, that result in the production of methane which is interchangeable with natural gas. Methanation is described by the following chemical equation,

$$CO + 3H_2 \rightarrow CH_4 + H_2O \quad . \tag{3}$$

This reaction is carried out in the presence of a catalyst that is extremely sensitive to sulfur poisoning which requires that even trace amounts of sulfur be removed in the gas purification system. The methane produced by this reaction is more expensive than the methane produced directly by hydrogasification because of the higher oxygen consumption and lower thermal efficiency to produce methane by methanation compared to hydrogasification.

*In fact, one of the synthesis products from this reaction can be gasoline. With conditions and catalysts adjusted to yield gasoline, the particular synthesis is called the Fischer-Tropsch reaction and is currently employed in the Republic of South Africa for the production of motor fuel from their native coal.

Therefore, another goal of the developing process technology is to maximize the fraction of methane produced by hydrogasification compared to that produced by methanation.

Gasification Processes Now Under Development

As mentioned before, only processes for which pilot plant commitments have been made are listed.

Bi Gas Process – Bituminous Coal Research, Inc. This is a high-pressure (1000 to 1500 psig) process that uses a two-stage gasifier with the lower stage and for the production of synthesis gas from char. The hot (2700°F) synthesis gas entrains and hydrogasifies raw coal in an upper stage. No pretreatment of coal is necessary because of the very high temperature of the synthesis gas and the low concentration of coal in the entrained reactor.

Hygas Process – Institute of Gas Technology. There are three versions of the Hygas Process currently under development. Two of the versions (Steam-Iron and Electrothermal) use different ways of generating heat for the production of synthesis gas, while the third uses the more conventional steam-oxygen gasification system. The Hygas system also uses two stages to effect coal conversion. This plant was completed in 1971 and is now operating. The process scheme calls for pretreating "caking" coals with air to allow their utilization.

Synthane Process – United States Bureau of Mines. The Synthane Process is one of the simplest of the newer processes. It employs three integrated stages to convert the coal. The top one is a pretreating zone where coking coals are treated with a steam-oxygen mixture, they then fall into a hydrogasification-devolatilization zone where approximately half the methane is produced, and the char from the hydrogasification zone then falls into a synthesis gas zone into which a steam-oxygen mixture is fed. The char exiting this last zone is then used to provide the necessary fuel for the plant.

CO_2 Acceptor Process – Consolidation Coal Company. This process eliminates the use of oxygen by using calcined dolomite as a heat carrier. The hot calcined dolomite is mixed with lignite and steam and synthesis gas is generated via chemical reaction (1). The char, resulting from the gasification step, is burned in another vessel with air in the presence of the dolomite which is calcined and recycled to the gasification vessel. This process is now being evaluated in a pilot plant.

Agglomerating Bed Gasifier – Batelle/Union Carbide. This process also eliminates the use of oxygen by using hot coal ash to provide the heat for synthesis gas generation via equation (1). Combustion of char is carried out in a fluid bed at conditions where the ash forms small agglomerates which are then transferred to a vessel where fresh coal and steam are added to generate the synthesis gas. A portion of the agglomerated ash is recycled to the combustor to help control the combustor temperature in the correct range for the formation of discrete ash agglomerates. A pilot plant is scheduled to begin operation in the fall of 1974.

Hydrane Process – United States Bureau of Mines. This process allows the utilization of coal without the necessity of pretreating by dropping the coal through a dilute-phase reactor in which it passes through its plastic temperature zone. The feed gas to this reactor stage is a mixture of hydrogen and methane formed in a fluid-bed reactor into which the char from the dilute-phase reactor falls. Feed gas to the fluid-bed reactor is hydrogen and the hydrogen-methane mixture produced by reaction (2) is used to hydrogasify the raw coal fed into the dilute-phase reactor. Because 95% of the methane is produced directly rather than by methanation, the Hydrane Process appears to offer the lowest cost route to methane. The dilute phase has been operated extensively and a small pilot plant, incorporating both fluid and dilute-phase reactors, has been built and is now undergoing shakedown operations.

State of the Art in Gasification

Unlike coal liquefaction, commercial gasification technology exists and is practiced where petroleum and natural gas are in short supply. The major commercial gasification systems are the Lurgi and the Koppers-Totzek systems. For the United States, the Lurgi is the most practical system because it operates at pressures up to 400 psig which reduces the compression costs for injecting the gas into distribution systems which operate at approximately 1000 psig and it produces a substantial amount of methane directly because of the high pressure and contacting system employed.

Thus, the availability of at least two commercial gasification systems means that we can expect to see coal converted to pipeline gas before it is converted to a liquid fuel. However, in spite of these commercially available processes, there is still a strong driving force to develop technology that will allow lower cost pipeline gas to be produced. The developing systems should offer the following.

1. Ability to utilize finer coal sizes and a wider variety of American coal.

2. Ability to reduce or eliminate oxygen consumption.

3. Allow the use of simpler reactors and fewer reactor trains for a commercial plant.

The major problem still to be overcome in coal gasification is the development of an adequate solids feeding system to allow coal to be pressurized from atmospheric pressure to the 1000 to 1500 psig pressure required to reduce compression and gas purification costs and maximize the yield of methane formed by direct hydrogasification.

SUMMARY AND CONCLUSIONS

Circumstances are forcing the United States to utilize its large reserves of coal to make up for shortfalls in petroleum and natural gas supply. This has resulted in active R&D programs to develop the most economic way of converting coal to supplementary pipeline gas and liquid fuels.

In liquefaction, outside of the Fischer-Tropsch Process currently utilized in South Africa, no commercial technology exists for converting coal to liquid fuels. In order to make the large commercial liquefaction plants feasible, the rapid development of equipment, expertise, and process concepts suitable for such large-scale operation will be required.

In gasification, on the other hand, there is at least one commercial process (Lurgi) that can be used to produce pipeline quality gas. Nevertheless, there is a strong driving force to develop technologies that will be more suited to the types of American coals and the large-scale operations contemplated for this industry.

SESSION IV – ENERGY ANALYSES AND THE ENVIRONMENT

Chairman – Mr. Bernard Zeffert

Edgewood Arsenal

BENEFICIAL USES OF WASTE HEAT FROM STEAM ELECTRIC POWER PLANTS

by

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Industrial Pollution Control Division, EPA

INTRODUCTION

Waste heat is the heat contained in the condenser discharge effluent from the normal operation of steam electric turbines. Beneficial use of this heat must either reduce the thermal water pollution directly or provide economic compensation to help offset the cost of cooling devices.[1]

SOURCE AND MAGNITUDE OF THE PROBLEM

The United States is the most energy-consuming nation in the world. With only 6% of the total population, this country accounts for more than one-third of the world energy consumption. Annual national energy use is 70 quadrillion Btu's (which equals 2.8 billion tons of coal, or 616 billion gallons of oil, or 70 trillion cubic feet of natural gas). Gross energy use per capita has risen from 229 million Btu's in 1947 to 333.3 million Btu's in 1971.

Steam Electric Utilities in 1970 in the United States and Puerto Rico withdrew 170 billion gallons per day of water (bgd) from the various water bodies. In 1980 this figure is estimated to increase to 193 bgd.[2] This is not consumptive use, rather, almost all of this is eventually returned to its source with only one bgd lost through evaporation and other losses. However, the water is 10° to 30°F hotter than it was prior to withdrawal.

Although the 1970 to 1980 water withdrawal increase quoted above does not seem like much, if present trends continue through the year 2020, it is estimated that water withdrawals will amount to 914 bgd, an increase of a factor of more than 5.

With legislation already in existence[3] which requires the eventual reduction and possibly the total elimination of waste heat dumping into the nation's waterways by 1985, what is the nation to do about it? One opinion has been expressed that it was strictly a legislative act which defined waste heat as a pollutant in water, so it would be just as easy to pass new legislation to repeal this definition and go ahead and dump waste heat.

It isn't that easy. The justification for that legislation in the first place included substantial data proving beyond any doubt that heat is damaging to the ecological systems in most cases. This is not true in every case, but in most. Therefore, it is not reasonable or logical to consider repeal, because this legislation, or a variation of it which defines waste heat in water as a pollutant, is here to stay.

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[1] Effects and Methods of Control of Thermal Discharges. Report to the Congress by the Environmental Protection Agency in accordance with Section 104(t) of the Federal Water Pollution Control Act Amendments of 1972. Part 2.

[2] Water Policies for the Future. Final Report to the President and to the Congress of the United States by the National Water Commission, Arlington, Virginia. US Government Printing Office, Washington, DC. June 1973.

[3] Federal Water Pollution Control Act Amendments of 1972. PL 92-500, October 18, 1972. Available in Edgewood Arsenal Building 3330, Technical Library.

STATUS OF THE ART

In 1973 out of a total installed capacity of 340×10^3 megawatts, 230×10^3 megawatts actually had no installed equipment for control of waste heat.[4] In other words industries, over two-thirds of them, made use of once-through cooling. This amounts to 67% of the installed capacity. These data only consider units of 25 megawatts or larger.

Regulations will eventually define heated-aquatic-effluent standards or "effluent limitation guidelines." However, one of the reasons that elaborate cooling devices will not be required on each and every power plant is the cost factor. Whether or not cooling devices are imposed on each individual power plant will be influenced, aside from the costs involved, by plant age, plant size, and also ownership of available space.

BENEFICIAL USES

Table 1 lists some of the major beneficial uses of waste heat.[1]

Table 1. Uses of Waste Heat

Energy component	Supply temperature* °C (°F)
Low-temperature heat	
Space heat	93 (200)
Domestic hot water	93 (200)
Adsorption air conditioning	121 (250)
Water distillation	129 (265)
Industry	149 (300)
Snow and ice melting	100 (212)
Transportation	149 (300)
Waste heat	
Secondary sewage treatment	35 (95)
Agriculture	35 (95)
Aquaculture	35 (95)

*Approximate minimum temperature of transmitted steam or hot water.

The uses of waste heat in agriculture has been the subject of a demonstration cost-sharing grant performed by the Eugene Water and Electric Board, Vitro Engineering and EPA in Eugene, Oregon. In the aquacultural uses, TVA has been the leader, although some of these have also been performed in the private sector. TVA has also done some experimental work using heated waste water in agricultural greenhouses.

[4] Steam Electric Powerplants. Burns and Roe, Inc., Engineers and Constructors, Oradell, New York. June 1973.

EPA PROGRAM

In general, the EPA energy objectives have been stated to be:

1. Minimize growth of energy demand.

2. Promote efficiency and conservation.

3. Make energy-environment impact assessments on the basis of the entire energy chain – extraction, processing, transportation and use.

4. Work toward decreasing reliance on fossil fuels.

5. Maximize pollution control technology and increase energy flexibility by increasing electricity end uses, particularly in transportation.

6. Encourage clean use of domestic coal.

7. Promote development of exotic energy sources – solar, geothermal, fusion.

8. Oppose projects which promise quick energy but at high environmental cost.

With these in mind, we shall confine our attention to the beneficial uses of thermal discharge. To these we should add "generate power without using any cooling water."

Section 104(t) of the legislation requires studies which "shall consider methods of minimizing adverse effects and maximizing beneficial effects of thermal discharges."

The use of waste heat in sewage treatment plants is just now being given serious consideration. Preliminary studies have shown that biological processing of sewage can be increased by a factor of ten by raising the temperature by using low-grade waste heat. In the past, EPA has funded a study for New York State which will evaluate the acceleration of secondary sewage-processing heating. These studies may indicate a potential use for heated condenser-discharge water but it is very doubtful that this use could be anything more than a supplementary application because of the large quantities of waste heat produced versus what can be readily used.

Another possible use of waste heat is in agricultural applications. It appears technically feasible to use waste hot water in open-field agriculture and for temperature control in greenhouses and animal shelters. The question of economic feasibility is as yet unanswered.

Some of the potential benefits to accrue from the use of waste heat for temperature control in open-field agriculture are: prevention of damage caused by temperature extremes, extension of the growing season, acceleration of growth, and the improvement of crop quality. A significant pilot demonstration of these benefits has been performed at the previously mentioned Eugene, Oregon, demonstration. Thermal water at 32° to 60°C (90° to 140°F) from a nearby Weyerhaeuser Paper and Pulp Company plant is sprayed over orchards and crops to provide frost protection, plant and crop cooling, and irrigation on 69 hectares (170 acres) of farm land. Results indicate: (1) that thermal water has a definite advantage over cold water in providing complete plant frost protection, (2) that thermal water through evaporation is effective in plant cooling, and (3) that thermal water for irrigation is as good as normal cold water. Preliminary economics of this multiuse system also appear favorable as shown in table 2.[1]

Table 2. Total Annual Cost Per 0.4 Hectares (acre) for Three-Crop Protection and Irrigation Systems[1]

System	Annual fixed cost	Annual operational cost	Total annual cost
Multiuse	$81.54	$ 11.20	$ 92.74
Solid fuel and hand-move irrigation	13.59	265.05	278.64
Central distribution	74.75	295.05	369.80

The importance of soil temperature to plant growth has long been recognized although basic knowledge in this area is somewhat limited. A number of programs currently underway are investigating the potential benefits of heating soils with waste hot water. An experimental project supported by the State of Oregon, the USDA, and the Pacific Power and Light Company showed that soil warming, in this case using electric heating cables, gave increased crop yields averaging 40%.

OTHER PROGRAMS

Experiments at TVA have shown the combined effects of soil heating and subirrigation to be most favorable in combination as indicated in table 3.[1]

Table 3. Effects of Soil Heating and Subirrigation on Vegetable Production, Muscle Shoals, Alabama, 1971[1]

Yield Tonne Per Hectare (Tons per Acre)				
Crop	Irrigation		No irrigation	
	Heat	No heat	Heat	No heat
String beans	18.2 (8.1)	9.0 (4.0)	15.5 (6.9)	6.1 (2.7)
Sweet corn	20.2 (9.0)	11.2 (5.0)	13.9 (6.2)	7.2 (3.2)
Summer squash	68.6 (30.6)	60.3 (26.9)	46.2 (20.6)	39.5 (17.6)

Further experimental work on subsurface irrigation is being performed at the Western Washington Research and Extension Center, while economic studies of these systems are in progress at Washington State University.

The utilization of thermal water in open-field agricultural applications appears to offer significant benefits although several problem areas remain. Of great importance is the long-term implications of waste heat applications for soil management, disease, and pest control. A more basic problem is the economic risk associated with implementing pilot-scale research to large farms over extended years of operation. The problem of radioactive contamination of agricultural products from the use of cooling water from nuclear power plants must be solved and may require special precautions which could, in turn, diminish the economic attractiveness of these proposed ventures. Other pollutional side-effects could include changes in temperature or chemical characteristics of ground water and the spreading of pesticides. The advantages of greenhouses for the cultivation of vegetables have long been acknowledged. These include larger crops, bigger yields, the ability to culture crops year round, and the ability to provide optimal environmental conditions for crop growth. Although the costs of producing vegetables in greenhouses vary with location, the two largest single operating costs are always labor and fuel. Heating costs for commercial greenhouse operations, utilizing fossil fuels, can be as much as $4900 to $27,200 per hectare ($2000 to $11,000 per acre.[1]

The University of Arizona and TVA, among others, have performed work on the applicability of heating and cooling greenhouses using low-level waste heat. At the University of Arizona's Puerto Penasco (Sonora, Mexico) greenhouse facilities, about 300 cultivars of vegetables and six cultivars of strawberries have been tested for growth and yield characteristics. Results have shown that the cultivars developed in hot, humid areas respond best to the environments maintained in these greenhouses. Also, generally speaking, most vegetables tend to be more succulent and brittle and crop yields are much higher than is usually the case when they are grown outside. Table 4[1] presents a comparison of marketable crop yields grown under different conditions. It should be noted that the yields in the table were obtained under high light conditions which would not prevail in the northern latitudes. The success to date of this facility has led to the development of a two-hectare (5-acre) greenhouse complex which is now in operation for the sheikdom of Abu-Dhabi.

TVA and Oak Ridge National Laboratory are collaborating on an experimental greenhouse facility located adjacent to TVA's Browns Ferry Nuclear Power Plant. The greenhouse is to be cooled in the summer by evaporating the 32°C (90°F) water from the turbine condenser with once-through air and heated in the winter by operating the evaporative pads in an air-recirculating mode. Objectives of this demonstration are to prove out the scaled-up heating and cooling system developed by ORNL, which utilizes the waste hot water to establish the feasibility of producing vegetables commercially in the environment provided, and to evaluate the economic viability and commercial potential for large-scale greenhouse operations.[1]

One of the major problems associated with the use of waste heat in greenhouse applications is that of financing and marketing the large quantities of produce raised in any greenhouse complex that might conceivably utilize a small portion of the waste heat available from modern power plant operations. It is estimated, for example, that glass houses which could use one-fourth of the waste heat from a 1000-megawatt power plant would require a capital investment of about $25 million and would occupy some 101 hectares (250 acres).[1] Other problem areas include the possibility of increased fungus growth and the spread of bacteria in the near 100%-humid greenhouse atmospheres, the effect of various water treatment chemicals used in the cooling water system on greenhouse plants, and the possibility of radioactive contamination of the greenhouse produce by the cooling water discharged from nuclear power plants.

The same system for heating and cooling greenhouses has potential application for environmental control in livestock shelters. Proper temperature, humidity, and ventilation control in these shelters has been shown to decrease feed consumption and increase livestock productivity. An analysis of broiler and swine production costs indicate that feed costs represent 65% of total production expenses. It has been suggested that the use of waste heat could reduce fuel bills and increase feed efficiency and growth rate for both hogs and broilers by providing optimal temperature conditions.[1] Also, TVA has further proposed a livestock waste-recycling system in which algae would be cultivated on the nutrients from manures in a series of ponds and, subsequently, harvested and processed into a high-protein feed source for livestock.

Significant problems must be overcome before waste heat will find extensive utilization for environmental control in animal shelters. One of the problems is insufficient knowledge on the technical and economic feasibility of such systems, particularly the large production operations envisioned. Estimates have been made that current commercial operations are two or three orders of magnitude smaller than would be required to use 10% of the waste heat from a 1000 Mwe power plant. Disease, odor, waste disposal, and land use are critical

Table 4. A Comparison of Marketable Crop Yields

PUERTO PENASCO GREENHOUSES			COMPARATIVE DATA FOR UNITED STATES	
Kind of vegetable	Marketable yield 0.4 hectare or 1 acre per year	Approximate average yield from greenhouses	Approximate average yield outdoors/0.4 hectare or 1 acre per year	Good yield outdoors/0.4 hectare or 1 acre per year
Cucumber (European type)*				
Fall crop	144 tonne (158 tons)	–	4 tonne (4.4 tons)	11 tonne (12 tons)
Spring crop	159 tonne (175 tons)			
Eggplant				
Fall crop	60 tonne (66 tons)*	–	6.5 tonne (7 tons)	7.5 tonne (8.3 tons)
Spring crop	60 tonne (66 tons)*			
Lettuce				
Bib and leaf				
Winter crop	3500 ctn @ 2 dozen	3500 ctn		
Okra				
Winter crop	36 tonne (40 tons)	–	–	4.5 tonne (5 tons)
Peppers				
Bell				
Winter crop	13.6 tonne (15 tons)	–	4.2 tonne (4.7 tons)	5.7 tonne (6.3 tons)
Radish				
Winter crop	40,000 bunches	40,000 bunches	–	20,000 bunches
Tomato				
Fall crop	68 tonne (75 tons)	36.3 tonne (40 tons)	6.2 tonne (6.8 tons)	27.2 tonne (30 tons)
Spring crop	54.4 tonne (60 tons)	54.4 tonne (60 tons)	–	–

*Based on a harvest period of 90 days.

problems facing such large-scale production operations. Geographical concentration of livestock production facilities and seasonal demands for waste heat also appear to be limitations to widespread utilization of this concept. Problems with radioactivity (in the case of nuclear-plant-supplied waste heat) and biocides in condenser cooling water still must be resolved.

Another potential area for direct utilization of waste heat from power plants is aquaculture. The Japanese have pioneered in this area since their initial culture experiments at the Sendai Power Plant in 1964. Presently five other demonstration programs, utilizing heated effluent from fossil-fueled plants, and a multi-species demonstration project at the Tokai-Mura Nuclear Power Station are under development. Much of the basis for the use of waste hot water for aquacultural applications has been established through years of extensive Japanese fish-culturing experience. In 1967, aquacultural products in Japan represented 6% of the total catch and 15% of the total value.[1]

Of the 2500 known fish species, less than 1% have been successfully cultured at all and probably less than 0.5% have been intensively cultured as in animal husbandry. The simplest operation is the stocking of fish in pond cultures. Yields of a few hundred kg per hectare (pounds per acre) can be sustained on the natural food elements available in the water system. With nutrient enrichment by nitrogen and phosphorous fertilization, these yields can be increased to 670 kg per hectare year (600 pounds per acre year) and, with supplemental feeding, the yields can be as high as 1800 to 2700 kg per hectare year (1600 to 2400 pounds per acre year). At this stocking level, however, buildup of fish wastes, biological oxygen demand, and low dissolved oxygen content can lead to an overwhelming imbalance of the aquatic system. Catfish, currently the most widely cultured fish in the United States (24.5 million kg or 11.1 million pounds in 1970), have traditionally been raised on a seasonal basis in pond cultures.

Dynamic culture systems offer a greater degree of environmental control and, consequently, offer larger potential yields. Such systems as the confinement of fish in cages submerged in a natural water body or cooling channel and flowing water culture, in which fish are stocked in multiple channels, can allow a high degree of environmental control. Yields of 224,000 to 900,000 kg per hectare year (200,000 to 800,000 pounds per acre year) have been reported for these systems. A successful commercial trout operation of flowing water culture is the Thousand Springs Trout Company in Buhl, Idaho. This year-round operation is made possible by a 950,000 ℓ/min (250,000 gpm) supply of constant temperature 15.6°C (60°F) springwater which is distributed into high-population-density channels. Rainbow trout yields of 224,000 to 450,000 kg per hectare year (200,000 to 400,000 pounds per acre year) have been obtained. Several seawater species have been cultured on a seasonal, partially environmental-controlled basis. This includes raft culture of oysters and mussels, cage culture of yellowtail, and the culture of shrimp, blue crab, abalone, squid, lobster, and salmon.[1] The Japanese have also cultured several varieties of seaweed and algae.

Basic research has shown that optimal fish growth can be realized with the maintaining of proper temperatures. The concept of using power plant coolant to maintain optimal temperatures for fish cultures was first demonstrated in Japan and more recently has been investigated in the United States. The oyster farms of Northport, Long Island have produced oysters on a commercial basis in the heated effluent of Long Island Light Company. By proper environmental control, selective breeding, and seeding of oysters, this commercial operation has reduced by 1-1/2 years the 4-year oyster-growing cycle. The use of thermal effluent permits accelerated growth over a 4- to 6-month period during which the oysters would normally be experiencing little growth.

Catfish culturing in thermal waters has also been practiced at one small-scale commercial operation. This operation uses the thermal discharge canal of a fossil-fueled plant of the Texas Electric Service Company at Lake Colorado City, Texas, for the cage culturing of catfish. Other pilot investigations are being performed in covered channels using discharge water from a TVA steam plant in Gallatin, Tennessee, and at Houston Lighting and Power Company's Cedar Bayou Power Plant.

Cultivation of shrimp in heated effluent is being investigated at Florida Power Corporation's Crystal River site and at the Turkey Point facility of Florida Power and Light Company. Perhaps the largest shrimp-farming venture is that of Marifarms, Inc., of Panama City, Florida. This operation uses technology originally developed in

Japan to cultivate and harvest some 1000 hectares (2500 acres) of sea-level impoundments and 240 hectares (600 acres) of land ponds. This operation utilizes the warm water from the local power plant to maintain water temperatures in the winter months.

Numerous other small-scale efforts in the United States have just now begun with the culturing of lobsters in warm effluents. The Japanese, as noted earlier, have pioneered in the efforts to use waste warm water for fish cultivation purposes. Present operations include the culturing of shrimp, eel, yellowtail, seabream, ayn, and whitefish.

Several problem areas will have to be resolved for the development of large-scale thermal aquaculture facilities. One of the major questions is that of economic feasibility and a dependable market for large-scale operations. There have been several instances of technically successful operations which failed because of an inadequate marketing arrangement. Another significant problem for large-scale operations is the treatment of fish wastes and the requirement for adequate water-reconditioning systems, including aeration, sedimentation, screening, chemical coagulation, and pH control. In a recent study, it was also found that 114 hatcheries were releasing 21 tonne (23 tons) of biological oxygen demand (BOD) per day – equivalent to a city of 270,000 people.[1] More work is needed to determine optimal growth conditions and food substances in order to maximize feed conversion to flesh. Although cultured species in adequately controlled environments do convert nutritionally balanced feed to flesh as efficiently or better than do chicken broilers, suitable feed formulation has been developed in this country only for the mass culture of rainbow trout. The possibility of radioactive contamination of cultured species is another problem area which must be adequately solved if utilization of thermal water from nuclear power plants is to be achieved. It is also unlikely that any aquaculture facility could utilize all the waste heat from a typical modern day steam electric power plant. Furthermore, it is possible in certain locations that ambient water temperatures may preclude the use of any waste heat during the critical (for power plant waste heat disposal) summer months. Thermal aquaculture does not necessarily reduce the heat disposal problem of the power plant but it may provide additional profitability.

In summary, the direct utilization of power plant waste heat has potential application in the areas of secondary sewage treatment, agriculture, and aquaculture although each of these areas shares a number of problems along with several proposed uses such as ice-free shipping lanes which have not gone beyond the preliminary investigation state. One of the major problems is the high distribution costs associated with pumping large quantities of low-grade waste hot water. In an effort to minimize these costs, facilities would have to be located in the reactor exclusive area if the waste heat were supplied by a nuclear power plant, and this introduces questions of radioactive contamination by condenser cooling waters. Another problem is the large mismatch which exists between the amount of heat available from a typical steam electric plant and that which could be used by any process or combination of processes. This mismatch may not impose any penalty on the potential user, but the ability of the utility to market only a small fraction of the heat produced may reduce the incentive for utility participation and steer the utility along the more conventional lines of auxiliary cooling towers. The demand for heat is also largely seasonal in nature and may further restrict the usefulness of these applications. Of critical importance to the utility is the capability of disposing of waste heat in summer months.

Finally, and most importantly, the economics of such applications have not yet been adequately demonstrated on a large commercial-scale basis. The planning, financing, and coordination of a commercial-size operation have yet to be delineated.

The concept of "total energy" is not entirely new. Over 400 commercial, industrial, and institutional installations fulfill their heat requirements and electricity demands with total energy systems.[1] These systems utilize relatively small-capacity gas turbines and diesel engines to generate their power requirements. The total energy complex, in contrast, would involve the use of high-quality steam from the steam electric power plant cycle to provide both process heat and electricity.

Figure 1[1] shows conceptually some of the different ways of using the energy input to a steam turbine power system. The top illustration is the familiar steam-electric generating system with about 40% of the input energy converted to electricity and 60% dissipated to the environment as waste warm water (or air). The second diagram shows that extraction of some of the steam before or after it has generated some electricity makes better use of the total energy input. Thirty-five percent of the energy is converted to electricity and 35% is extracted for other purposes and would replace energy that would otherwise be supplied by another source. Energy utilization in this case is about 70% with the remainder being dissipated to the environment. The third diagram illustrates the ultimate in energy utilization if there is a very large need for low temperature heat. In this case the steam expansion in the turbine is stopped short of full expansion to produce the process heat required. Energy utilization in this case would be very nearly 100%.

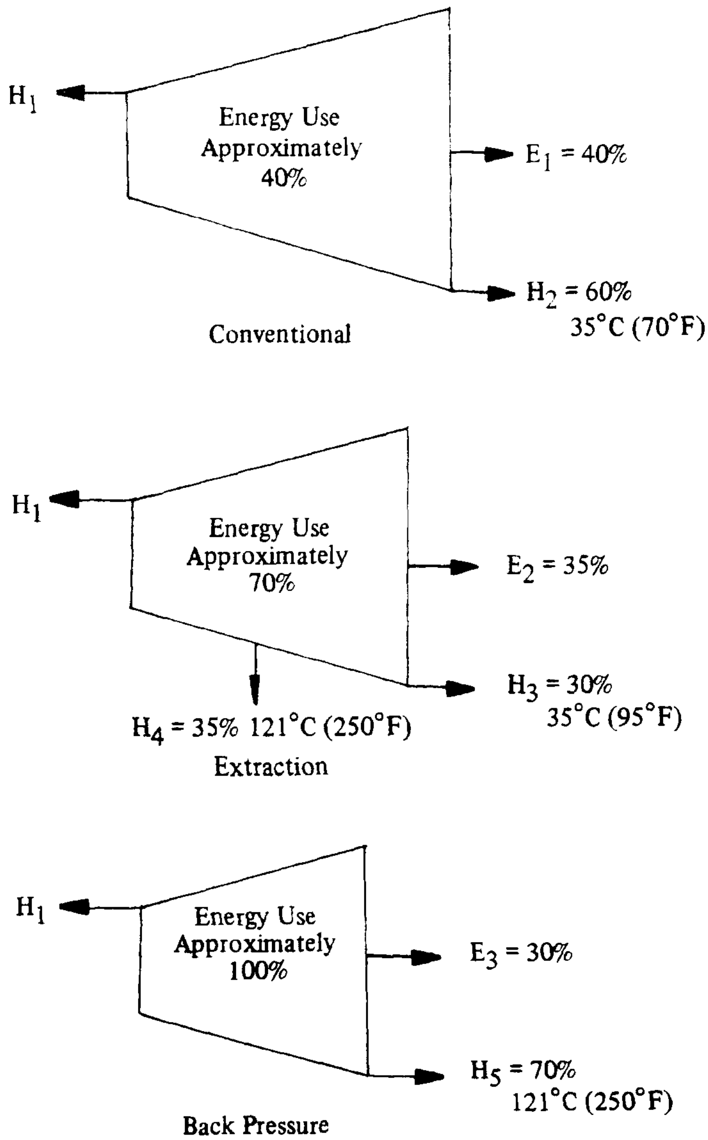

Figure 1. Conventional and Dual-Purpose Steam Turbine Performance

Extraction and back-pressure turbine concepts for the production of process heat are not at all new. District-heating systems, both in this country and abroad, have used these systems in providing power and space heat for many years,[1] with Consolidated Edison of New York being the largest district-heating system in this country. Industrial process steam has also been supplied by combination heat and electric power plants as in the case of Consumer Power's Midland Nuclear Plant.[1] What is new, however, is the concept of combining the turbine systems into a composite arrangement so as to fully integrate power generation and process heat requirements for an active city and its industry, commerce, and residences.

Oak Ridge National Laboratory has done extensive work in this area, and has conceptualized a number of integrated systems for the production and use of electricity and heat.[1] In one study, a reference city with a population of 400,000 and a climate similar to Philadelphia was investigated. It was found that heat supplied from a steam extraction turbine could be competitive with present heat sources. The combined utilization of thermal energy and electricity in this total energy complex resulted in significant reductions in thermal emissions and air pollution and in the conservation of fossil-fuel resources.

The institutional, financial, and management problems facing the establishment of such an integrated-total-energy complex are enormous. Transmission and distribution costs (a function of population density) for the delivery of thermal energy are a major determinant in the economic viability of any total energy complex and will probably dictate a case-by-case investigation. Nevertheless, the potential benefits of a total energy complex warrant serious consideration. The total energy complex could very well be a solution to several environmental problems in the reduction of thermal pollution from power plants.

ENERGY SYSTEMS ANALYSIS

by

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INTRODUCTION

There is a statement concerning energy which has been repeated so often that it has nearly lost its ability to capture attention, much less to shock. The tragedy is that it has been around so long that the indifferent reaction is justified. The statement goes:

> "The United States has 6% of the world's population and consumes 35% of the planet's total energy and minerals production. The average American uses as much energy in a few days as half the world's individuals consume in one year."

It is the purpose of my presentation to examine the energy situation as a problem in systems analysis and to emphasize some actions which may assist in coping with the situation, and in assessing its relationship to national defense preparedness.

In our limited time, we will (1) review current and projected energy usage, (2) summarize future and potential energy sources, (3) comment on the application and implications of systems analysis to the energy problem, and (4) refer to the relationship of the energy problem to the United States defense preparedness, as appropriate.

ENERGY USE PATTERNS

In order to provide a perspective on the energy problem, we consider first the energy use rates for the year 1970 (shown in table 1) as representative of recent demand patterns. Note that the domestic supply is adequate except in the case of hydrocarbons (oil and gas) where about 12% of our total energy needs is dependent on imports.

The form in which the national energy is utilized is shown in table 2. Note that 21% goes into production of electricity and 72.5% directly into end uses. In table 3, the end use distribution is shown distributed among three main categories. Note the large proportion used by industry. It will also be observed that efficiency, as reflected by useful energy desired, varies widely to the disadvantage of transportation.

The distribution of energy according to source, which goes into each end use category, is shown in table 4. Note the predominance of gas and oil as sources for residential, commercial, and industrial, and the nearly total dependence of transportation on oil.

In order to assist in visualizing the changing pattern of energy sources, a historical view is shown in the figure. Note the nearly constant proportion of hydropower and the disappearance of once-dominant fuel wood. The contribution of coal, strongly dominant in the first third of the century and peaking in the 1920's, is now down to half of its World War II level. During this same period, since the war the contribution of natural gas has increased the most, approximately doubling.

Table 1. United States Energy Use Rates – 1970

Supply	Million barrels per day oil equivalent (MB/DOE)	Percent of total
Nuclear	0.11	0.33
Hydroelectric	0.4	1.18
Geothermal	0.003	0.009
Natural gas		
Imports	0.5	1.48
Domestic	11.5	34.0
Coal	7.4	21.9
Oil		
Imports	3.5	10.4
Domestic	10.4	30.8
Total	33.8	100.0

Source: Joint Committee for Atomic Energy (JCAE) – 1973

Table 2. United States Energy Use Patterns – 1970

Form of use	MB/DOE*	Percent of total energy used
Electricity production	7.1	21.0
(To end use)	(2.5)	(7.4)
(Conversion loss)	(4.6)	(13.6)
Direct to end use	24.5	72.5
Exports and field use	2.2	6.5
Total	33.8	100.0

Source: Joint Committee for Atomic Energy (JCAE) – 1973

*Million barrels per day oil equivalent.

Table 3. United States Energy End Uses – 1970

End use	MB/DOE*	Percent of total end use	Percent efficiency as useful energy
Residential and commercial	7.5	27.8	74.7
Industrial	9.9	36.6	74.7
Transportation	7.7	28.4	24.7
Nonenergy	1.9	7.1	–
Total	27.0		

Source: Joint Committee for Atomic Energy (JCAE) – 1973

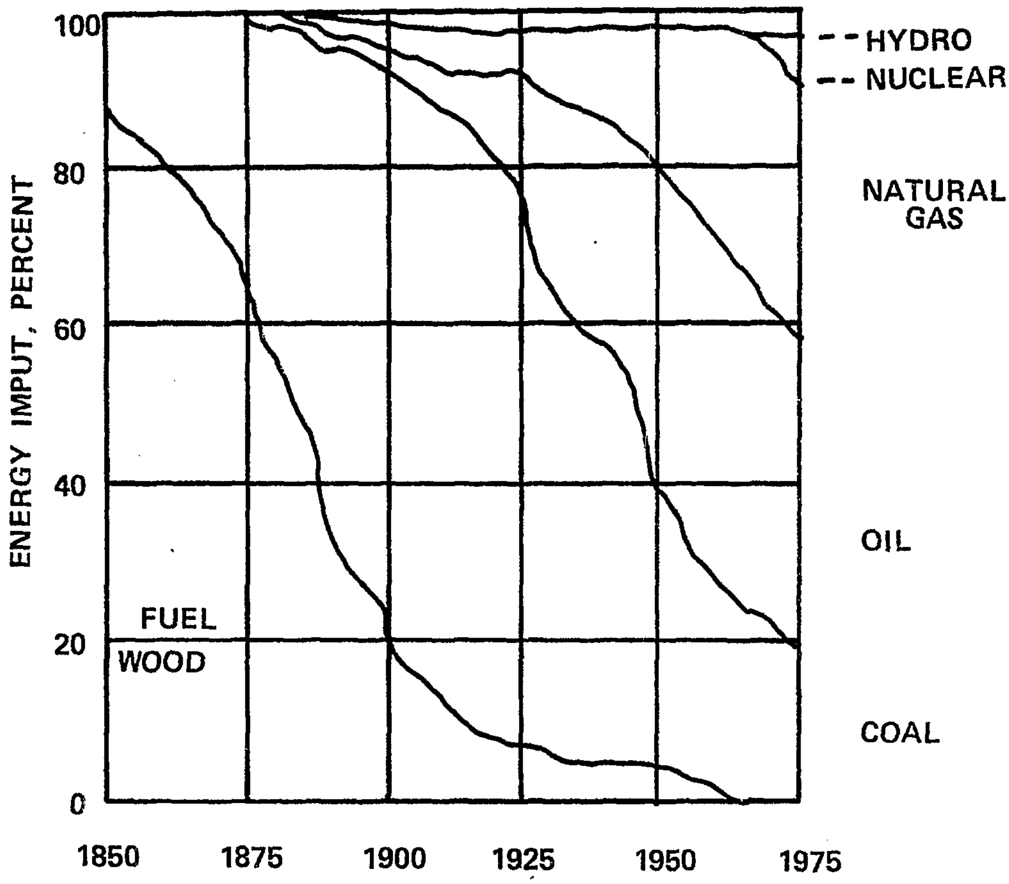
* Million barrels per day oil equivalent.

Table 4. United States Energy End-Use Sources – 1970

End use	Source	MB/DOE*	Percent of end use input
Electricity	Nuclear	0.11	1.5
	Hydroelectric	0.4	5.6
	Natural gas	1.9	26.8
	Coal	3.7	52.0
	Oil	1.0	14.1
Residential and commercial	Electricity	1.3	17.3
	Natural gas	3.5	46.6
	Oil	2.5	33.4
	Coal	0.2	2.7
Industrial	Electricity	1.2	12.1
	Natural gas	4.6	46.5
	Coal	2.5	25.2
	Oil	1.6	16.2
Transportation	Natural Gas	0.3	3.8
	Oil	7.4	96.2
Nonenergy	Natural gas	0.3	15.6
	Coal	0.1	5.2
	Oil	1.5	79.2

Source: Joint Committee for Atomic Energy (JCAE) – 1973

*Million barrels per day oil equivalent.



Source: Scientific American, September 1971

Figure. Historical View of Changing Energy Pattern

We can superimpose, on this changing pattern of energy source contributions, a view of the rate of increase in magnitude of energy demands. Representative values are shown in table 5 according to end use category. These values support the frequently quoted current rates of increase in the 4% to 6% per year range. We further note that the rate of increase for electricity production is equivalent to doubling the requirement in 10 years. An overall energy-use rate increase of 5% equates to a doubling of total energy requirements in approximately 14 years.

Table 5. United States Energy-Consumption Rates of Increase in Recent Years

Use	Increase, percent per year, various periods		
	1961-1965	1965-1969	1971-1972
Electricity			
Production	7.0	8.6	7.1
Transportation	–	6.4	5.7
Residential, commercial, and industrial	–	3.7	4.1

Source: Bureau of Mines and Scientific American, September 1971

This rate of increase of energy use, if continued, presents us with a systems problem of great magnitude and potential significance to the course of history. The immediate questions are:

1. What alternative sources of energy can be developed domestically?

2. In what time scale?

3. In what quantity?

4. In what form relatable to end uses?

5. What consequences must be anticipated if potential sources fail to meet demand?

We will examine briefly these questions in order to develop a perspective regarding the outlook.

FUTURE POTENTIAL ENERGY SOURCES

NUCLEAR

The Atomic Energy Commission (AEC) forecast in March 1973 that nuclear power, now providing about 4% of the country's electricity, will account for 60% by the end of the century. It also forecast that, in the year 2000, one-half of all the energy used will be electrical compared to the present approximately one-quarter. This corresponds to a use of electrical energy in 2000 of five times the present rate.

The forecast for nuclear capacity at intermediate points is shown in table 6 and corresponds to the AEC "accelerated program."

Table 6. Projected United States Nuclear-Energy Production of Electricity

Year	Electricity production	
	Billion kw	MB/DOE*
1973	0.0147	0.42
1980	0.132	3.82
1985	0.280	8.1
2000	1.20	34.7

Source: Atomic Energy Commission, Washington, DC, 1139/72

*Million barrels per day oil equivalent.

Since nuclear plants achievable by the early 1980's are those already in planning, little further acceleration is possible. The AEC projection assumes also that, at year 2000, 0.4 out of 1.2-billion-kw-installed capacity will be breeder-type. Continued slippage of this program and intense environmentalist reaction should be noted. If these factors prevail, conventional reactors could substitute. In either case, the question of nuclear fuel availability is raised.

Problems of enrichment plant capacity have received much attention recently. Equally important is the availability of the fuel raw material. The AEC forecast a requirement of 2.4 million tons of U_3O_8 through year 2000. The 1973 reserves at $8.00 per pound were 273,000 tons; the estimated potential as yet undiscovered was 450,000 tons. At a price of $15.00 per pound, reserves plus estimated potential are 1.5 million tons – or about 1 million tons short of requirements.

It was in anticipation of this shortfall in projected fuel availability that GEOMET has developed patented and proprietary techniques of exploration for remote detection of subsurface uranium ore bodies, and is now engaged in exploration and property development. Early discoveries give us some confidence that important changes in domestic fuel availability can be achieved.

In view of the above considerations, it must be concluded that the forecast of nuclear energy supply through 2000 represents the best it will be possible to achieve.

COAL

Coal has been heralded by Secretary of the Interior, Rogers Morton, as our ace-in-the-hole to meet the energy crisis. The arguments for greatly expanding the utilization of coal are persuasive, particularly for the remainder of the century. The estimated three trillion tons of domestic coal, frequently cited as a 3000-year supply at today's rate of consumption, is impressive. Secretary Morton rightly advocates a major national program in coal. The time factor is a crucial issue, however, despite the enormity of reserves.

The problems are well known:

1. Environmental opposition to massive strip-mining programs and to surface caving resulting from underground mining.

2. Lack of effective methods for removal of sulfur (typically in excess of 3%).

3. Serious difficulty of inducing workers into underground mining as an occupation.

4. Lack of effective coal gasification and liquefaction techniques (now prohibitively costly and wasteful of 25% of the energy content).

5. Decline of the industry and the associated distribution and transportation system. Drill rigs, crews, and equipment for exploration and for mining-property development and evaluation are in extreme short supply as both the uranium and coal programs accelerate beyond customary norms.

Projections of energy supply from coal, in the face of these difficulties, are uncertain. The Joint Committee on Atomic Energy (JCAE) projection of 11.8 million barrels per day oil equivalent (MB/DOE) for 1985 is contrasted with Secretary Morton's target of 1500 million tons a year, or approximately 18 MB/DOE by 1980. Secretary Morton estimates $10 billion over the next 5 years as a minimum to accomplish his objective. The entire Federal 5-year energy R&D program is of this magnitude, with about $2 billion allocated to the coal program over this period. Unless four times this amount is added in implementation funds and unless very early R&D results are available, it seems highly unlikely such a target could be met. We therefore accept for the moment the JCAE forecast through 1980, recognizing that it could be improved somewhat through intensive effort.

Forecasts beyond 1980 are subject to significant uncertainty, but it is apparent that continued growth of coal supplies will continue. We do not believe that Secretary Morton's target is likely to be achieved in view of the Federal energy budget already set and difficult to upgrade without an important lag time. We therefore conclude that the best achievable represents a compromise between extrapolation of the linear increase between 1970 and 1980, and a paralleling of the nuclear contribution (which is already on an accelerating curve with its foundations in national intent dating 10 years back). On this basis, Secretary Morton's goal of 18 MB/DOE) would be achieved, not in 1980 but more nearly in 1995.

In a longer range time scale, coal has a very great potential along with uranium for a century or two beyond year 2000. It has been estimated that all but the first and last 10% of our coal resources will be utilized between the years 2000 and 2300.

OIL

The projected supply of oil from domestic sources is dependent on several factors, including various assumptions concerning economic motivating forces and environmental opposition. Estimates of future supplies are given in table 7 and reflect the Alaska North Slope oil.

Table 7. Projected United States Usage of Oil

Year	MB/DOE*			
	JCAE** estimate			Shell Oil estimate total
	Import	Domestic	Total	
1960	1.9	1.9	9.7	9
1970	3.5	10.4	13.9	14
1980	10.8	11.5	22.3	23
1985	14.6	11.0	25.6	28
1990	–	–	–	33

*Million barrels per day oil equivalent.

**Joint Committee on Atomic Energy.

The close correspondence between the totals projected by JCAE and Shell probably reflects the dependence of the Government on the oil industry and the National Petroleum Council for data.

The projection of oil imports is probably meaningless and should be considered to represent a deficit which cannot be filled by domestic sources. We will return to this subject later, as it relates to projected demand.

NATURAL GAS

Projected usage of natural gas is shown in table 8. These projections suggest relatively level supplies through the century with increasing dependence on imports.

HYDROELECTRIC

Hydroelectric power, accounting for only a little over 1% of the nation's total energy in 1970, will remain approximately constant. There are not enough sites left to exploit to constitute a significant contribution.

GEOTHERMAL

Geothermal energy represents a potentially important source for the future. However, this source will not become a major factor in this century.

Table 8. Projected United States Usage of Natural Gas

Year	MB/DOE*			
	JCAE** estimate			Shell Oil estimate total
	Import	Domestic	Total	
1960	0.1	6.4	6.5	6.0
1970	0.5	11.5	12.0	10.5
1980	1.8	8.5	10.3	11.5
1985	3.0	7.1	10.1	11.0
1990	–	–	–	10.0

*Million barrels per day oil equivalent.

**Joint Committee on Atomic Energy.

SOLAR ENERGY

The vast potential offered by solar energy is becoming widely recognized, but the technology for conversion into electricity on a large scale may be many years away.

Basic technology already exists to permit the use of solar energy for space heating, air conditioning, and water heating. In 1970 approximately 70% of all energy used in the residential and commercial categories was for these purposes. This amounts to about 5.25 MB/DOE, or about 20% of all end-use energy expended. However, the difficulty of introducing such a new development into the highly decentralized building industry on a wide basis is a serious limitation. The National Science Foundation/National Aeronautics and Space Administration (NSF/NASA) Solar Energy Panel judged that the probable impact would be installation of solar-powered systems on 10% of new buildings constructed in 1985 and 50% in 2000. This would correspond to 1% and 12% of total buildings, respectively. The resultant energy derived from this source then would be about 57,000 barrels per day oil equivalent in 1985, and one MB/DOE in 2000. National motivation of a massive retrofit program could improve these projections significantly.

SUMMARY OF SUPPLY/DEMAND OUTLOOK

The projected demand for energy would increase from the present oil equivalent of 36 million barrels per day to 120 million barrels by 2000 if the present rate of increase were to continue. Most projections estimate a demand between 90 and 95 million barrels by 2000. If demand were curtailed to as low as 82 MB/DOE for the year 2000, it is concluded by the JCAE that our way of life, economy, and national security would be threatened. This relationship, however, has received very little attention despite its being a critical variable in the overall problem. A target demand of 90 MB/DOE is assumed as the most realistic current estimate, and corresponds with the Department of Interior 1972 estimate.

The projected supplies are summarized from the preceding discussion, and compared with the projected demand in table 9.

Table 9. Summary of United States Supply/Demand Projections

Supply (MB/DOE)* by source	Year				
	1970	1980	1985	1990	2000
Nuclear	0.11	3.82	9.4	14.1	34.7
Coal	7.4	10.5	11.8	15.5	23.0
Domestic oil	10.4	11.5	11.0	10.0	10.0
Domestic gas	11.5	8.5	7.1	7.0	6.5
Hydroelectric	0.4	0.5	0.5	0.5	0.5
Total domestic supply	29.8	34.8	39.8	47.1	74.7
Demand	33.8	45.5	55.7	67.0	90.5
Deficit	4.0	10.7	15.9	19.9	15.8

*Million barrels per day oil equivalent.

If the functional demand is to be met, the deficits must be made up by a combination of imports, conservation practices, and development of domestic sources faster than projected here. Closing of the deficit gap is a many-sided strategic problem, and certainly presents one of the most gigantic systems-management challenges of all time.

THE IMPORT OPTION

The implications of a high and continuing level of dependence on imports is a fundamental concern. The current situation of oil embargoes by the Arab countries highlights our critical vulnerability to international political considerations and to rising awareness by the Arabs of a need to relate domestic planning to the finiteness of their own oil supplies.

Even in the short run, say to 1980, imported oil may not be available in sufficient quantity and may only be available at prices which impact adversely on the United States and the rest of the industrialized world.

The economic impact of relying on imports – assuming they were reliably available – is formidable. By 1980, with a deficit of 10.7 MB/DOE and oil at a conservative $8.00 per barrel, the cost of imports jumps from a recent $4.5 billion to $31 billion. By 1990, this would become $58 billion. Previous offsets in the balance of payments, through dividends returned to multinational companies, can be expected to disappear with nationalization of oil resources. At the important levels anticipated, this becomes an impossible situation.

The potential impact on the world economy and security is no less profound. The developing countries, if subject to the same prices, will face catastrophic consequences, especially where there are only limited exports with which to pay for oil.

Contrariwise, the exporting nations are faced with an embarrassment of riches. Using the projected world demand, $8 oil would provide $113 billion in revenue to the Oil-Producing and Exporting Countries (OPEC) in 1980, or $180 billion for $10 oil. According to the World Bank, after every possible expenditure on internal development and social security, the five Persian Gulf countries would acquire net foreign assets of about $280 billion out of total world reserves of no more than $400 billion. This situation would pose enormous problems. Payment to the OPEC in national currencies would risk devaluations or nonconvertibility. The means of payment for oil, which would remain attractive assets for the oil-producing countries, are difficult to conceive.

It appears that the producers are more likely to limit production rates while maintaining elevated prices. The world economy and security must remain threatened for decades. Probably no importing nation except the United States can live with this situation, and the United States is surely threatened in a world of depression and attendant political and social unrest.

In view of the magnitude of the economic burden to the United States if we depend on imports; e.g., a price rising from $4.5 to $58 billion in a bit over 15 years, the scale of attack on energy sources envisioned to date is probably far too little to be in proportion. A $10-billion R&D program over 5 years is small in comparison. Herman Kahn's proposal to develop the Canadian Athabaska tar sands under a $20 billion program to achieve 1.5 million barrels of oil per day is not on a sufficient scale and still does not provide domestic oil.

It may well be that we and the rest of the world can be protected from this global blackmail only if the United States takes the lead in developing exportable technology or energy fuels which permit economical utilization by those who have the needs. Such a stance would be no different from the country's dedication to nuclear weapons and associated systems as an umbrella of protection against world-wide aggression. Such a capability could depress the price of oil and increase its availability to the world to such an extent that our hypothetical "Energy Bomb" need never be used. It has been suggested that a capability for producing synthetic crude oil from coal might provide us with the first model of such an Energy Bomb. The realities of the coal program, and the massive capital investment requirements, may be well beyond the capacity of the nation, however.

THE CONSERVATION OPTION

Regarding conservation, we should distinguish between wasteful practices and extravagant living. The first is concerned with the efficiency of energy use, and the second with personal values and a way of life. Both are subject to conservation measures, although one is much less controversial than the other.

A study of conservation potential conducted by the Office of Emergency Preparedness, Executive Office of the President, concluded that the estimated energy demand for 1980 could be reduced by as much as 7.3 MB/DOE. This is to be contrasted with the 1980 deficit of 10.7 MB/DOE. Since detailed analyses of feasibility and consumer acceptance were not attempted, this value must be regarded as an upper limit. It is clear, however, that strong national attention will be given to this option so that realization of 40% of the potential seems a reasonable expectation. This would account for 2.9 MB/DOE or 27% of the 10.7 MB/DOE deficit in 1980.

The most significant conservation measures evaluated were:

1. Installation of improved insulation in new and old homes, and use of more efficient air conditioners. (We note that solar-energized systems act to augment the objectives of this conservation measure.)

2. Shift of intercity freight from trucks to rail, intercity passengers from air to rail and bus, and urban passengers from automobiles to motorized mass transit.

3. Introduction of more efficient industrial processes and equipment.

The potential of these measures by 1980 would be a reduction in demand by 2.4 MB/DOE in the residential and commercial category; 2.3 MB/DOE in transportation; and 2.6 MB/DOE in industry.

Since each of these categories is a growing component of the demand curve, it is assumed that a proportionate share of the deficit beyond 1980 could be absorbed through conservation measures.

The measures cited above represent an attack on wasteful practices, and impinge only moderately on the way of life. To the extent that the deficit gap cannot be closed by other measures, conservation is the only way out. The notion of conservation is a variable one and in the extreme could represent austerity and hardship. If invoked to this degree, clearly not only the way of life, but the quality of life also, will be affected.

THE OPTION OF MORE AGGRESSIVE DEVELOPMENT OF DOMESTIC SOURCES

The potential for domestic sources has already been discussed above and forecasts of significant increases in supply have been made.

These projections contemplate advances in nuclear and coal technology, and some increased domestic oil production. The impact of geothermal and solar sources within this century is negligible. Possible improvements in domestic natural gas supply through price relief, and even greater coal utilization consistent with a national emergency, may not be fully reflected. Nevertheless, the domestic deficit indicated in table 9, and ranging between 10 and 20 MB/DOE through the remainder of the century, will not be drastically reduced by these considerations.

While drastic reductions may not be possible, significant reductions may be. In light of all considerations, there may be greater possibilities for developing domestic supplies, provided a coherent national strategy were evident which could galvanize into focus the many concurrent approaches necessary. The strategy must deal adequately with the crisis in the short run, and enable the overall problem to be solved in the long run.

In the immediate future, priority must clearly be given to restoring imports. In the short run, expanded domestic production of oil and gas is the only available option. Nuclear energy has received strong support and in the end, whether by conventional reactors, breeders, or fusion methods, will assume dominance as a domestic source. But this is a long time away. Meanwhile, only coal, which has suffered neglect and is in the doldrums, emerges as susceptible to an all-out program offering realistic promise of bridging the gap.

Secretary Morton's proposal of $10 billion over the next 5 years, as a minimum requirement, may seem out of proportion in relation to the proposed Federal R&D budget for all energy sources of some $11 billion over the same time period. The Secretary's estimate of an appropriate commitment may be far too low, however, in view of the extreme economic and security impact of a critical United States dependence on imported oil. The projected dollar export for oil required to balance our energy deficit between 1970 and 1990 amounts to $622 billion. Against this cost, since almost all of it is negative balance of payments, it would seem that a far more ambitious program than that proposed by Secretary Morton is justified. The justification must rest, however, on a recognition of the world energy balance as a critical turning point in civilization far greater than the dramatic wars and destructive weapons to which we have become oriented.

CONSOLIDATED VIEW OF SUPPLY/DEMAND OPTIONS

To the extent that imports, conservation, and accelerated development measures cannot close the deficit gap indicated in table 9, the demand curve must remain unsatisfied and appropriate adjustments will occur – whether planned or unplanned. It is useful, therefore, to examine the degree to which these various measures, *if implemented*, can contribute to meeting the deficits.

Our projections up to this point have been based on what is technologically and logistically possible, and on reasonable assumptions concerning the present state of awareness and urgency which seems to be perceived rationally. Clearly, this is a potential feedback situation since, if current circumstances reasonably lead to the concluding of serious consequences, the state of awareness and urgency, and resultant actions, can be influenced.

Table 10 summarizes the potential for closing the deficit gap and is based on the following assumptions which, although possible to realize, cannot be considered probable in the present national posture:

1. Imports could be acquired at tolerable prices, but would be limited to 10% of the total energy demand.

2. Conservation measures would account for 27% of the deficit.

3. Additional domestic sources beyond those indicated in table 9 are possible only in the case of oil and gas production. Oil production would be increased over current and projected rates by 50%, and natural gas production would be maintained at the 1970 level in contrast to the projection of a continuing decline.

Table 10. Potential Contributions to Closing Supply/Demand Gap

Source of contribution	Amount, MB/DOE*		
	1980	1990	2000
Imports	4.5	6.7	9.0
Conservation	2.9	5.4	4.3
Aggressive domestic development			
Oil	5.0	5.0	5.0
Gas	3.0	4.5	5.0
Total potential contributions to deficit	15.4	21.6	23.3
Projected deficit before contributions	10.7	19.9	15.8

*Million barrels per day oil equivalent.

It is apparent from table 10 that the deficit gap is possible of closure without resorting to diminishing the projected demand. This possibility should not be confused with probability, since very serious problems are included. Thus, consider the following:

1. There is no assurance that, even under favorable political circumstances, an increasing level of imports over the coming decades could or would be supplied by the exporting nations, as shown.

2. There is grave doubt whether the straightforward but far-reaching conservation measures will be implemented; these could be too little and too late.

3. There is some question whether the increased oil production shown can be maintained – although this is probably the least questionable of our considerations, provided economic incentives are favorable and environmental resistance is tempered.

4. There is a serious question whether the continuing decline in natural gas production, projected in table 9, will be offset by increasing contributions as shown in table 10, so as to maintain the 1970 production level – unless gas prices are approximately tripled so as to justify an expansion in the costly exploration programs associated with deep (15,000 to 20,000 feet) source regions.

In summary, it appears that a deficit situation is most probable throughout the remainder of this century, with time lags in realizing the details of the problem, with recurrent "crises" as fluctuations in the deficit curve occur, and with continuing and deepening impact on the way of life. The potential impact on the way of life is the least studied aspect of the entire energy question, while most attention has been given to the technological potentials. Closely related to the neglect of social impact is the neglect of systems management aspects. Both deficiencies, of course, are a result of lack of awareness or ability to accept that a problem of major proportions is upon us. Unfortunately, the enchanting and hypnotizing discussion of exciting technological developments which is usually thrust upon the public, lay and professional alike, does not recognize the total implementation and logistic problem – neither the time scale nor the capital costs.

SYSTEMS ANALYSIS AND THE ENERGY PROBLEM

We have discussed various aspects of the energy system. It is apparent that, in the urgent pursuit of exploiting known energy sources and developing new ones, crucial decisions will be required whose implications into the future will be difficult to evaluate. The results of some of these decisions will not impact on our energy supply for years.

The requirement for a comprehensive program of systems analysis seems obvious. Moreover, there is a marked similarity to the problems which have been faced within the Department of Defense over the past quarter of a century. In the energy context there are multiple technological approaches available, just as in the defense context multiple weapons approaches are available. In each context the same generalities apply. Choices must be made and priorities assigned, relationships to subtargets and overall strategy defined, development and production time scales projected, relative costs and effectiveness evaluated; phasing and balancing among the options must be effected.

Conservation – the thoughtful and deliberate management and allocation of our energy resources – will remain as a critically important policy consideration, now and into the indefinite future. Nevertheless, the entire world lives in such a complex social, economic, and technological web that it is not immediately obvious what will happen in one place if we tug on a thread somewhere else. This is a characteristic problem in complex systems, and requires continuing and sophisticated study using the best analytical techniques available.

The vast body of systems analysis experience, techniques, concepts, and insights evolved within the defense framework, related to fundamental questions of national welfare, represent a valuable resource that must now be brought to the energy arena. We would like, therefore, to present a few observations concerning the application of systems analysis to the energy problem.

SOME CONCEPTS IN SYSTEMS ANALYSIS

In its simplest form, a system may be represented by a set of inputs, acting on an assemblage of elements with defined scope and structure, subject to specified boundary conditions and constraints, so as to produce certain outputs resulting from relationships throughout the assemblage, which relationships may be considered as transfer functions. In the usual situation the system is more complex than implied by this definition in that there are feedback influences operating among elements within the assemblage, as well as cycling back from output to input. The feedback effects within the assemblage can become very complex and, in the extreme, give rise to the even more difficult problem where the system can no longer be reasonably viewed as one system but rather must be treated as multiple interactive or even competing systems.

In the analysis of systems, several classes of techniques have proven to be of considerable value. These are:

1. Mathematical, representable by functional equations.

2. Denumerative, representable by numerical or tabular arrays.

3. Statistical, representable by empirical relationships and probabilistic in nature.

4. Simulation, meaning simulation of event sequences, and distinguished therefore from the other techniques which are, of course, all simulations of some kind.

5. Gaming, i.e., interactive play either between adversary systems, between a consciously directed system and a neutral but indeterminate state of nature, or between a consciously directed system and an interactive and potentially provokable system.

Finally, and most importantly as a necessary adjunct to analytic techniques, is the requirement for data. This more prosaic consideration is the most critical and usually attended to the least. Current concerns with respect to the truth of the oil situation underscore this fact.

As in all systems problems, there is a need to define the system and to recognize the existence of hierarchies of subsystems. The applicability of various analysis techniques depends strongly on the scope of the system defined. However, in the particular case of the energy system, additional aspects are of special importance. For example:

1. The technological system is only part of the problem and is not the crucial public concern. Impact on the public is the crucial concern.

2. What is the relevant scale of analysis? Is it global and long range (i.e., centuries)? Is it national (in an isolationist sense)? Is it local (in a community sense)? Or is it a blend of all of these and, if so, what are the relative priorities?

3. What are the crucial time perspectives on the problem? Tactical versus strategic? And what are the tradeoffs in priorities in R&D and implementation programs? True, the short-term tactical problem *must* be solved, but at what price in conservation, even privation, in the interest of a more viable and desirable long-term strategic solution?

Concerning these questions, certain potential applications seem worthy of note. A variety of lower level components of the system problem should be amenable to mathematical and statistical approaches which have been widely used in many contexts. Denumerative models may be of value in dealing with certain aspects of the problem on a national scale. Leontiev's input-output economic model of the United States is denumerative in nature and could possibly provide the disciplinary basis for tracking energy distribution and utilization throughout the economy. If a congruent pattern of energy transfer were developed, it could provide a technique for assessing the impact on the national economy of alterations in energy supply, distribution, and form in which available.

Simulation and gaming offer the advantage of flexibility and versatility in dealing with systems which are structured in a highly complex manner, and where interactions and feedback abound. No other techniques are capable of dealing with such situations.

Simulation has been widely used in conjunction with problems where the interaction is between an actor and a state of nature. In its simplest form this could involve the functioning of a mechanical system such as a satellite in a neutral, but not wholly predictable, environment. Our own involvement in designing more effective health-care delivery systems is an example where interaction with a population, but not adversary opposition, is involved.

Gaming has become highly developed in the context of military scenarios wherein two-sided conscious interaction occurs.

Important limitations on both simulation and gaming exist. In simulation, which is usually fully computerized, great flexibility is afforded in regard to inputs and parameters within the simulation structure. But the structure is fixed. And inevitably there arises the "what if" question which involves a somewhat different problem than initially contemplated, and which implicates not just changes in inputs and parameters, but changes in structures.

Similarly with gaming. Military gaming, even when computer-assisted and augmented by all of the other techniques, is a complex and cumbersome business. As a result, applications of gaming have almost invariably tended to be concerned with the evaluation of various tactics or strategies, but always within some fairly circumscribed set of principal assumptions within which the game is played and which, in effect, define the game. These I will refer to as boundary conditions. They will include such definitions as geographic region of play, policy regarding use of nuclear weapons, policy regarding civilian targets, policy regarding first strike, specification of who the enemy is and who his allies are, etc. When it is perceived how difficult and lengthy is the gaming of a single play within any defined set of the above conditions, and when this is compounded by repetitive series to explore a variety of inner detail and to replicate outcomes and develop distributions of outcomes, the logistics of such a technique is seen as enormous.

If we now impose the requirement to repeat all of this under a new set of boundary conditions, and to do so for a wide range of boundary conditions, gaming becomes incapable. It has been my observation that there is a need for a whole new body of technique capable of playing boundary conditions as the principal variables, and where the inner play for a given boundary condition is suppressed. That this capability is badly needed is evidenced by the many examples (perhaps most, if not all cases) where the effect of details in the game play are second order to the main outcome in relation to the effects of variation in boundary conditions. Yet, curiously, the predominant emphasis in military gaming has been the exhaustive and repetitive play of tactical-scale details with relatively little attention given to variations in the basic controlling assumptions under which the game is played.

Such problems have been long encountered and dealt with in the economic and financial areas. The notion of a budget possesses the potential for readily adapting to the equivalent of variations in boundary conditions. No assistance is provided by this discipline, however, as to how to conduct operations in order to meet the budget. Nevertheless, there is a philosophical analog here which has not been achieved in the systems analysis area. There is required a blending of the diagnostic emphasis in systems analysis with the budgeting emphasis in financial management.

The above diversion into concepts and capabilities of systems analysis is purposeful because of the complexity of the energy problem in all of its ramifications. The nature of the national energy supply problem involves alterations in the technological area, and in the international political and economic areas. It therefore requires methods capable of examining the effect of basic changes in boundary conditions. The impact of these changes involves potentially major changes in the United States culture and way of life. Methods are therefore required capable of projecting economic, sociological, and political resultants. Some of these impacts may be so deep as to be outside the normal range of recent analytical experience, and therefore may necessitate recourse to experiential analogs of various kinds.

Historical, sociological, political and anthropological analogs and experience are commonly resorted to in most of our society's decisions. There may be no other techniques sufficiently adaptable if stringent time limitations are imposed on decision, or if the system complexity is so great as to be unreachable by the usual so-called objective techniques. The analog techniques are also most often invoked to assist in structuring, articulating, and decomposing a complex problem into manageable pieces, sufficiently simplified as to be amenable to analytic and objective approaches.

There is evident a gray zone when considering the impact of variations in boundary conditions. The gray zone is that region where neither the objective, analytical techniques on the one hand, nor the subjective interpretation of historical, sociological, political, and anthropological analogs on the other, are capable of providing reliable solutions. Each approach has sufficient demonstrated value in the application regions adjacent to the gray zone, hence both must be pursued in bridging the gap. Simultaneously, however, new approaches capable of subsuming the whole are postulated as deserving a separate search for feasibility.

While we suggest equal attention be paid to both the analytical and experiential approaches, we also recognize that this is unlikely to happen. Hence we must appear as an advocate for systems analysis. Not because it is a superior instrument in the gray zone but because the history of its employment in this zone is so short and underdeveloped that the heretofore *only* approach, based on subjective evaluative analogs, has such a long history of experience in western thought as to be the automatically accepted approach. In consequence, the analytic methods are disadvantaged in respect of acceptance.

An observation needs to be made regarding the complementarity of the objective (analytic) and the subjective (historical/experiential analog) approaches. The objective approach has the advantage of involving checkable discipline. The derivations can be tracked and independently verified by others *relatively* uninfluenced by subjective attitudes, interpretations, and opinions. The major disadvantage, already noted, is the relative incapacity of known techniques for rapidly and efficiently responding to sudden changes in the nature and dimensions of the presented problem.

In contrast, the subjective approach suffers from the hazards of individual perspectives and anecdotal bias, and is generally undisciplined in a checkable sense. Nevertheless, the technique is as highly and instantly adaptable as the human mind itself. It serves to marshall the forces of history, experience, and transmitted human intuition with an efficiency which is very likely never to be achieved by objective analytic processes. Hopefully, the ultimate solution in the gray zone will be a combination of forces wherein subjectivity dominates in the formulation of the problem and in the articulation of strategies of approach, and where objectivity dominates in the critical evaluation of approaches and in the feedback of evaluational results.

SOME ASPECTS OF THE GLOBAL SYSTEM

Always of value in systems analysis is the concept of limiting conditions. One such consideration in relation to the entire global energy system may be touched on here. All of the fossil-fuel or nuclear energy produced on earth, whether wasted through inefficiency or expended as useful energy, ultimately is absorbed within the environment due to its low temperature, and therefore appears as thermal pollution. If the rate of increase of energy consumption (currently 5% per year world-wide) is assumed to be 4% per year, the energy dissipation into the environment would equal the 2×10^{21} Btu per year absorbed annually from the sun, in about 2200 A.D. At this rate of heat absorption by the environment, it has been estimated that the excess heat would be capable of causing the polar ice caps to begin to melt uncontrollably somewhere between 2090 and 2160 A.D. A relatively short period of 40 years would be required to melt the ice caps substantially, resulting in raising the sea level in excess of 150 feet.

The question of heat interchange within the oceans and the atmosphere, and resultant transfer to the ice caps is a very complex one, and any calculations of the distribution of excess heat to these environmental components must be regarded as tentative and order-of-magnitude only. While the time required for world-wide catastrophic events to initiate may be in some doubt, the predicted outcomes are inevitable. Such calculations, therefore, serve to indicate that unlimited energy sources will not solve the world's energy problems. There is a finite limit which the earth is capable of sustaining, and the current growth rate in energy consumption may approach this limit within a few generations.

The world-balance modelling of Professor Forester at M.I.T., and the controversial Club of Rome modelling studies by Professor Denis, emphasize the criticality of a limiting balance among basic world components such as population levels, productivity, environmental degradation, and quality of life. Deeply embedded in all of these considerations is the question of energy supply. These studies suggest that far-reaching systems analysis deserves greatly increased attention.

A host of other problems of global significance are much closer in time than the thermodynamic limit, and probably closer than the world-balance limit. These involve a variety of international considerations of an economic and political nature, which have been adverted to in the remarks above. Outstanding threats are new distortions in the world-wide distribution of assets arising out of marked changes in the pattern of balance of payments; precipitous disappointment and intensified dissatisfaction among the aspiring third-world countries as diminished global energy supplies and elevated energy prices drive them back from their precarious advances in national development; and the resultant challenge to world peace and security arising out of the unbalancing of forces and the potential world-wide depression, defeated expectations, and inevitable political unrest. The ultimate threat to United States security from these sources is probably far greater than the immediate concern of the Department of Defense which is, properly, being attended to in a highly organized way through its fuel conservation and readiness program.

SOME ASPECTS OF THE NATIONAL SYSTEM

Where energy and the implications of a shortage are concerned, it is difficult if not impossible to distinguish clearly among global, national, and community aspects. A continuum is involved which pervades all of these arbitrary distinctions. With this recognition in mind, some observations can be made which serve to illustrate the need for systems analysis in an area of application which is national in scope, which has the potential for far-reaching international impact, and where interactions are involved which require assessment and forethought.

Attention is invited to agriculture and the food system as a vital component of the United States economy. This area is analogous to others which might be examined and, interestingly, leads to similar recognitions and conclusions.

Agricultural production is dependent on energy, and the high food productivity of the United States is dependent on the availability of energy for use as motor fuel in tractors and for the production of fertilizers and pesticides. The energy consumed by the food cycle amounts to 12% of the national energy budget. The breakdown by principal category is as follows:

Agricultural production	2.91%
Processing and distribution	4.65%
Storage and preparation	4.44%
Total	12.0%

While fertilizer is not a large component of the total food-system energy requirement (about 4.3%, or 0.52% of the national energy budget), it is in short supply even now with our foretaste of energy deficiency. Some farmers in the United States midwest are predicting crop yields to be down 30% this year due to fertilizer shortage, stating that for the first time in their lives they are unable to obtain fertilizer in the quantities required. If this shortage were general and sustained, there would be important impacts on agricultural practices, and on gardening practices of the population at large. It seems that the impact of the energy shortage on all aspects of the food system will unquestionably contribute to further significant rises in food prices.

Following on the probable impact on agricultural practices, but more importantly on the gardening practices of the individual with its attendant impact on activities, orientation, and outlook, even deeper changes may be anticipated. Such influences as we anticipate here, particularly when taken together with influences deriving from other energy-deficient components of our lives, must inevitably promote important changes in the culture and attitudes of our people. In general, these influences must act in the direction of sobering us to the realities of life. While technology will continue to present opportunities and challenges for the future, values and perspectives will be profoundly influenced, thereby affecting the manner of acceptance and utilization. Frivolities, luxuries, and prodigalities will be forcefully minimized. An entirely new culture may be anticipated which reconciles the intuitive, subjective, and spiritual aspirations of man with the magnificent artfulness of his science and technology – currently largely uncontrolled and undirected.

Since a significant fraction of the world food supply is dependent on United States food exports and United States fertilizer exports, it follows that deep adjustments internally in the Nation, as alluded to above, may have important consequences throughout the world. It is too early to tell whether these consequences will be destructive through removal of direct aid, or healing through lessening of the cultural gap and outlook.

Embedded within these various considerations of the possible resultants of an energy deficiency, as reflected in the agricultural and food system, are numerous problems concerned with priorities, choices and allocations. Rational and comprehensive approaches to these complex problems can be developed only through the use of disciplined, analytic processes.

CONCLUDING REMARKS

It appears that there is a high probability that the energy shortage will persist at least through the remainder of the century; and that, despite occasional periods of temporary relief, the shortage will become increasingly severe.

Current short-range considerations must be pursued on an emergency and ad hoc basis in order to maintain national integrity. Planning and initiation of longer range approaches, such as those contemplated in the 5-year Energy R&D program, must continue on the basis of the best data and judgment currently available. Development of domestic energy sources, even more aggressively than heretofore proposed, should be seriously considered.

Even though the above actions are taken, there will be a residual energy deficit of significant proportions which will express itself through economic and cultural impact. This impact will include the effect of accommodating environmental considerations. It will be felt primarily as a remission of the present culture of personal comfort and convenience in the United States – which is unique in the history of the world – and an enforced acceptance of new values and standards. This need not involve simple regression to the standards of an earlier individualized agrarian economy but, presumably, will be a new adaption which hybridizes a healthier set of moral and personal concepts with the realities of a more advanced industrial and technological society.

In recognition of the purpose of this symposium, it is noted, perhaps unnecessarily, that the objectives of the Association with respect to national defense preparedness are inextricably interwoven with the impact – short and long range – of the energy situation. This impact involves not only our direct military capability, but also the economic and cultural viability of the nation, and the interrelationship of this viability with the rest of the world.

In view of the long-range nature of managing the energy situation, there will be a continuing requirement for decisions at all levels. Historically, we know from our experience in the national defense area that decades were required to develop and apply appropriate systems analysis techniques. Hopefully, this experience can significantly shorten the time required to achieve effective application to the energy problem. There would seem to be an obligation on the part of those who have participated in the unique history of defense applications to work toward the formulation and institution of a structure whereby this experience can be transferred to the energy area, and to participate in a wide-ranging program in support of this objective.

A major systems analysis program should be initiated now so that in the next several years it can catch up with, and improve on, the current best judgments so they can be brought closer to accord with a more studied systems view of the total problem. There is no public evidence to my knowledge that such a coordinated program has been initiated or planned.

Coping with the long-range energy problem is one of the foremost requirements of our day. The establishment of a Federal Energy Office, whatever its deficiencies might be, provides a focus of responsibility for the study and development of far-reaching policy. It follows, therefore, that this office or any successor policy agency should act to bring about, in the appropriate framework, these necessary functions. Extensive precedent has been provided by the defense establishment. It initiated the application of operations research during World War II. The supporting aerospace industry carried these origins over into a highly developed field of systems analysis following the war. The Defense Department incorporated these methods into its ongoing operations as a normal way of conducting its business.

The civil sector has widely adopted these approaches and methods in uncounted applications. It seems timely for a broad-based operations research and systems analysis program to be built up, oriented toward all aspects of the national energy problem.

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