

# ADEQUACY OF U.S. OIL AND GAS RESERVES

---

718

## HEARING BEFORE THE JOINT ECONOMIC COMMITTEE CONGRESS OF THE UNITED STATES NINETY-FOURTH CONGRESS FIRST SESSION

---

FEBRUARY 25, 1975

---

Printed for the use of the Joint Economic Committee



U.S. GOVERNMENT PRINTING OFFICE

57-220 0

WASHINGTON : 1975

---

For sale by the Superintendent of Documents, U.S. Government Printing Office  
Washington, D.C. 20402 - Price 90 cents

81

## JOINT ECONOMIC COMMITTEE

(Created pursuant to sec. 5(a) of Public Law 304, 79th Cong.)

HUBERT H. HUMPHREY, Minnesota, *Chairman*

WRIGHT PATMAN, Texas, *Vice Chairman*

### SENATE

JOHN SPARKMAN, Alabama  
WILLIAM PROXMIRE, Wisconsin  
ABRAHAM RIBICOFF, Connecticut  
LLOYD M. BENTSEN, Jr., Texas  
EDWARD M. KENNEDY, Massachusetts  
JACOB K. JAVITS, New York  
CHARLES H. PERCY, Illinois  
ROBERT TAFT, Jr., Ohio  
PAUL J. FANNIN, Arizona

### HOUSE OF REPRESENTATIVES

RICHARD BOLLING, Missouri  
HENRY S. REUSS, Wisconsin  
WILLIAM S. MOORHEAD, Pennsylvania  
LEE H. HAMILTON, Indiana  
GILLIS W. LONG, Louisiana  
CLARENCE J. BROWN, Ohio  
GARRY BROWN, Michigan  
MARGARET M. HECKLER, Massachusetts  
JOHN H. ROUSSELOT, California

JOHN R. STARK, *Executive Director*

JOHN R. KARLIK, *Senior Economist*

LOUGHLIN F. MCHUGH, *Senior Economist*

COURTENAY M. SLATER, *Senior Economist*

RICHARD F. KAUFMAN, *General Counsel*

### ECONOMISTS

WILLIAM A. COX  
SARAH JACKSON  
CARL V. SEARS

LUCY A. FALCONE  
JERRY J. JASINOWSKI  
GEORGE R. TYLER

ROBERT D. HAMRIN  
L. DOUGLAS LEE  
LARRY YUSPEH

### MINORITY

LESLIE J. BANDER

GEORGE D. KRUMBHAAR, Jr. (Counsel)

# CONTENTS

## WITNESSES AND STATEMENTS

TUESDAY, FEBRUARY 25, 1975

Humphrey, Hon. Hubert H., chairman of the Joint Economic Committee: Opening statement.....	Page 1
Carlson, Hon. Jack W., Assistant Secretary for Energy and Minerals, Department of the Interior, accompanied by Vincent E. McKelvey, Director, U.S. Geological Survey; and Richard Meyer, U.S. Geological Survey.....	2
Emery, Kenneth, Chairman, Panel on Estimation of Mineral Reserves and Resources, National Academy of Sciences.....	12
Moody, John D., member, Panel on Estimation of Mineral Reserves and Resources, National Academy of Sciences.....	27
Perry, Harry, consultant.....	28

## SUBMISSIONS FOR THE RECORD

TUESDAY, FEBRUARY 25, 1975

Carlson, Hon. Jack W., et al.: Response of Vincent E. McKelvey to written questions posed by Chairman Humphrey.....	58
Emery, Kenneth: Excerpt from a report entitled "Mineral Resources and the Environment," by the Committee on Mineral Resources and the Environment (COMRATE), Commission on Natural Resources, National Research Council, National Academy of Sciences.....	14
Response to written questions posed by Chairman Humphrey.....	60
Humphrey, Hon. Hubert H.: Letter from Hon. John C. Sawhill, Administrator, Federal Energy Administration, dated December 4, 1974, responding to written questions posed by Chairman Humphrey regarding the FEA's policies for crude oil pricing as they relate to incentives for further exploration and development of domestic crude oil reserves.....	32
Study entitled "The Long Run Solution to Our Energy Problem, by W. N. Peach, University of Oklahoma.....	62

(III)

# ADEQUACY OF U.S. OIL AND GAS RESERVES

TUESDAY, FEBRUARY 25, 1975

CONGRESS OF THE UNITED STATES,  
JOINT ECONOMIC COMMITTEE,  
*Washington, D.C.*

The committee met, pursuant to notice, at 10:55 a.m., in room 4221, Dirksen Senate Office Building, Hon. Hubert H. Humphrey (chairman of the committee) presiding.

Present: Senators Humphrey and Javits; and Representative Brown of Ohio.

Also present: William A. Cox, professional staff member; Michael J. Runde, administrative assistant; Leslie J. Bander, minority economist; and George D. Krumbhaar, Jr., minority counsel.

Senator JAVITS [presiding]. The committee will come to order.

Chairman Humphrey has asked me to open the hearing. He will be here in about 15 or 20 minutes. I will read his opening statement into the record at this point.

## OPENING STATEMENT OF CHAIRMAN HUMPHREY

I have called this hearing to clarify one of the most fundamental elements of information needed to formulate an enlightened national energy policy. I refer to information on the size of America's remaining oil and gas resources and the resulting projections of attainable future production rates.

The U.S. Geological Survey has made various recent estimates that place recoverable U.S. resources of crude oil and natural gas liquids in the range of 200 to 400 billion barrels, including those under the Continental Shelf. If we take the midpoint of this range—300 billion barrels—then we have enough oil to continue present output rates for about 80 years and potentially to produce at significantly higher rates for a substantial period. Based on these and other data, the Project Independence blueprint estimated that U.S. oil output could be increased by more than 50 percent by 1985 and could be sustained at such levels for several years. This would enable us to reduce or eliminate import dependence over this period.

A new report by the National Academy of Sciences, however, amasses evidence from various sources that potentially recoverable U.S. oil resources are much less than indicated by the Geological Survey. It reaches an analogous conclusion for natural gas and concludes that "a large increase in U.S. annual production of petroleum and natural gas is very unlikely." It also warns that world resources of oil and gas will be seriously depleted by the end of the century if present production and consumption trends continue.

If the Geological Survey is correct, then increased oil and gas production may grant the Nation a longer period to reduce dependence on oil and gas while still holding our oil imports to a prudent level. If the National Academy panel is correct, however, then it becomes far more urgent to find acceptable ways to mine and utilize more of the Nation's coal; to get more nuclear capacity into operation; to substitute solar power for fossil fuels wherever feasible; to push energy conservation more rapidly; and to accelerate research and development on revolutionary technologies to relieve our dependence on conventional energy sources.

So the issue is drawn. Some of the main participants in this debate will testify before the committee this morning. I hope that they can clarify the basis for the diverse estimates of oil and gas resources and suggest ways to reduce the extent of uncertainty. I hope also that they can guide Congress in taking proper account of the unavoidable uncertainty of such estimates in its effort to formulate policy on energy production and conservation and on energy research and development for the medium- and long-term future.

Our first witness is Hon. Jack W. Carlson, the Assistant Secretary for Energy and Minerals. Mr. Carlson, will you identify for the record who is with you.

**STATEMENT OF HON. JACK W. CARLSON, ASSISTANT SECRETARY  
FOR ENERGY AND MINERALS, DEPARTMENT OF THE INTERIOR,  
ACCOMPANIED BY VINCENT E. McKELVEY, DIRECTOR, U.S.  
GEOLOGICAL SURVEY; AND RICHARD MEYER, U.S. GEOLOGICAL  
SURVEY**

Mr. CARLSON. Yes, Senator. I am pleased to have with me a distinguished geologist, Mr. Vincent E. McKelvey, who is Director of the U.S. Geological Survey, and Richard Meyer, who is also with the Geological Survey and who will be pleased to respond to the Committee. And if it pleases you, I would like to start with a two- or three-page opening statement.

Senator JAVITS. Please do.

Mr. CARLSON. The subject you have asked us to testify on is estimates of U.S. petroleum resources, and it is of particular interest to everybody at the present time, especially the undiscovered resources. This subject deals with uncertainty, but we do have some basis other than random factors to make those kinds of estimates. The factors that we consider range from past exploration and production experience to surface analysis of favorable geologic structures.

The committee has asked some experts to comment on the various techniques and we are pleased to join with them. The professional testimony from the executive branch will be given by my distinguished colleague, Mr. Vincent McKelvey, Director of the U.S. Geological Survey.

However, I would like to make a few general comments. First, the uncertainty characteristics of resource estimates argues for more data. The proposed budget for the Geological Survey includes a request for additional funds for estimating oil and gas resources. I am sure the deliberation of this committee will reinforce our request.

Second, the wide range of estimates by the various experts substantiates the need felt by both the Congress and the President, to improve our estimates of resources. The President's proposed energy program recognizes the need to explore the frontier areas of the Outer Continental Shelf in the Atlantic, Pacific, and around the State of Alaska; and Naval Petroleum Reserve No. 4 located in northern Alaska; and Naval Petroleum Reserve No. 1 located in California. The most rapid method to improve our knowledge of resources is to encourage the private sector to explore, develop, and produce oil. Until we actually drill exploratory wells, we not know with significant confidence the extent of reserves in these areas. And, even after exploratory wells are drilled, reserve estimates will still vary as subsequent productive wells add to our knowledge of each reservoir.

Third, the current range of estimates of resources, using either low or high estimates, clearly indicates the need to consider other sources of energy in the long run. The emphasis by the Federal Government on this Nation's plentiful supply of coal is appropriate. The known reserves of coal are huge. In addition, improving technology, e.g., liquefaction and gasification, to use coal better is a good investment. So are R.&D. investments to develop other alternatives, such as nuclear, solar, geothermal, and others.

Fourth, the current range of estimates, using low or high estimates, clearly indicates the need to conserve oil and gas for the long run. Deregulation of new natural gas and old crude oil is vitally important to reduce low priority uses and encourage alternative sources of energy, yet promote the development of the available natural gas and oil resources.

Fifth, the change in energy prices caused by the price-fixing behavior of the OPEC countries raises questions about the improvement of our estimates. For example, many of the methodologies used for the estimates of recoverable resources depend on the market price. Inasmuch as price has fluctuated more widely than during any time period prior to October 1973, a review of alternative price levels and their impact on the estimates of recoverable resources is important.

Consequently, I feel the following steps are appropriate:

A paper should be prepared, describing the techniques used for estimating resources. The testimony of experts before this committee will be one important source. Other sources should include recognized authorities not appearing before the committee today. The U.S. Geological Survey is truly an important source of information on this subject.

A meeting of the experts should be called to discuss the paper and techniques for improving resource estimates, including the impact of alternative prices. Promising techniques should be tested. Changes in estimates should be published.

Such a review could be very helpful this year. We would be pleased to share the results with this committee. However, I should caution the committee that the range of uncertainty may still persist even after this intensive review. Uncertainty is best circumscribed by actual drilling and development of promising oil and gas reservoirs.

Senator, I would like to turn to my colleague, Mr. Vincent McKelvey, to get into the more technical aspects of the subject you have asked us to testify about.

Senator JAVITS. Mr. McKelvey is recognized.

Mr. McKELVEY. Thank you, Senator. I welcome the opportunity to meet with you today to discuss estimates of domestic reserves and resources of oil and gas. I know that one of your chief concerns is the meaning of the wide difference among various estimates to which the National Academy's Committee on Mineral Resources and the Environment called attention in its recent report on "Mineral resources and the Environment," and I will explain the reasons for those differences. I will also indicate what I consider to be the significance of these various reserve resource estimates and will briefly describe the work in progress on these general problems in the Geological Survey. Some misconceptions have developed over some of these topics, and I hope I may be able to clarify them.

Senator, my statement is a lengthy one. Because of the complexity and the importance of the subject, it would be helpful if I read it in its entirety, but I will be glad to excerpt it simply giving the most important parts if you would prefer.

Senator JAVITS. Well, Chairman Humphrey is not here yet; so I think it would be just as well if you went ahead, and when he comes he can decide.

Mr. McKELVEY. Thank you, Senator.

One of the first things I would like to address, Senator, is the nature of the task of estimating unknown, and almost unknowable, quantities. Mineral deposits are for the most part hidden in the earth, and we can only measure that part of the total which we have actually discovered—and even that quite imperfectly. The dimensions of the undiscovered portion can only be guessed at through inductive reasoning based on evidence available from the previous record of exploration and discovery, geologic comparisons of explored and unexplored rocks, and a variety of assumptions as to how and where oil and gas accumulations might be formed. Obviously such a process does not yield definitive results, and estimates by equally competent individuals can differ widely because of differing methodology and treatment of the available evidence.

More than 10 years ago, when the controversy over the difference in magnitude of undiscovered oil and gas resources began to develop, the then Geological Survey Director, Mr. Thomas B. Nolan, said that no Survey estimates of potential resources should be regarded as official estimates, because there can be no such thing when it comes to an appraisal of the unknown. I would modify Mr. Nolan's statement only to suggest that while any estimate of undiscovered resources that is published under the U.S.G.S. imprimatur is *prima facie* an official estimate, it is by no means an *ex cathedra* pronouncement of inviolable truth, nor does it even represent a consensus of scientific opinion within the Survey itself.

Of the nine estimates considered by the National Academy Committee, five were prepared by members of the Geological Survey, including the estimates at both the low and high end of the range. Moreover, the chairman of the committee, Mr. Brian Skinner, who obviously associates himself with the Academy Committee's own middle ground estimates, is a former member of the Geological Survey, still working with us on a when-actually-employed basis; and the co-chairman of the committee, Mr. Richard Doell, is a full-time member of the Geological Survey.

There is thus no unanimity of viewpoint within the Geological Survey on a single "best approach" to this problem. Scientific groups are like this, including the National Academy. The experimental character of scientific inquiry, the tentative nature of its findings, and the free-ranging thought processes of scientists themselves practically guarantee a diversity of opinion on every proposition that cannot be reduced to mathematical proof. Thus while the Survey reviews and periodically revises estimates of undiscovered mineral resources, hopefully to achieve with each revision a closer approximation of the truth, we recognize and welcome the existence of other estimates as being useful contributions to the solution of a most difficult and elusive problem.

While I personally have stressed the importance and need to develop assessment methodology to the point where wide agreement is reached, and fully recognize the need in planning and policymaking for greater certainty in our understanding of our resource potential, at this stage in the exploration of this difficult problem I believe that the disagreements both in the Survey and in the profession at large are healthy from a scientific standpoint. As I will elaborate later, I also believe that the estimates available, divergent as they are, have significant implications for policy.

As background for discussion of the estimates, I would like to give the problem some perspective by briefly discussing the nature of mineral resources and the reliability of estimates of their magnitude. Mineral resources are naturally occurring substances that are usable or potentially usable by man. At any point in time, their magnitude is fixed, but it changes overtime with the development of men's ability to use natural substances that were not usable previously, and his ability to find, extract, refine, and transport materials that could not be produced economically before.

The magnitude of usable resources is also strongly influenced by prices and costs, not only those of the commodities in question but those of substitute or competing materials available from other sources. Laws, regulations, and national policies governing the production and use of resources also influence the magnitude of the materials that may be producible and usable at any given time. Resources are thus not fixed in quantity but change over time as the result of changes in scientific understanding, technology, economics, and public policy.

In discussing potential supplies of minerals, it is important to distinguish between reserves and resources. Reserves are materials that have actually been discovered by drilling or some other form of exploration and are known to be commercially recoverable under present economic and technologic conditions. In a broad context, as when we speak of the mineral resources of a nation, those identified reserves are also included in the term resources. But resources also include those identified materials that are too costly or too inaccessible to produce economically now, and they also include undiscovered deposits of both presently minable and unminable quality. Over time, resources may become reserves when exploration leads to new discoveries of minable materials or when technologic advance or price increase makes it possible to produce materials that formerly could not be recovered economically.



For these reasons, estimates of the magnitude of mineral resources necessarily have a wide range of uncertainty and they are likely to change over time. Not only is it difficult to determine the extent of deposits not yet fully explored, and impossible to ascertain exactly the extent of those not yet discovered, but it is also difficult, if not impossible, to predict the course and extent of technologic development and external economic conditions that may determine the marketability and usability of various kinds of materials in the future.

With respect now to the estimates of undiscovered resources discussed by the National Academy committee, three general approaches have been involved in making such estimates. One is to compare the volume of unexplored rock believed to be generally favorable for the occurrence of petroleum to the volume of rock that has already been explored and to make some extrapolation of oil and gas found in the explored area to the unexplored. This is the method that was utilized by Mr. T. A. Hendricks of the Survey in 1965 and by Mr. P. K. Theobald and others of the Survey in 1972, and coupled with a basin-by-basin analysis and some other modifications it was the approach taken by W. W. Mallory and others of the Survey's resource appraisal group in 1974 in the estimates that in the Academy's report are attributed to me. It is also the principal method used by the National Petroleum Council in its analysis of potential petroleum resources and published in its report on, U.S. Energy Outlook in 1973—Oil and Gas Availability.

A second approach consists of the geologic analysis of what are called plays in petroleum exploration jargon; that is, specific targets that have been identified as highly prospective for the occurrence of petroleum. This was the method primarily used by the Mobil Oil Company in its 1974 estimates, which I believe are described in the Academy's report as those of company D.

The third general approach consists of the use of historical production and discovery data to develop projections based upon past trends. This is the approach utilized by Mr. M. K. Hubbert of the Geological Survey who has made several kinds of projections that agree closely with one another. Incidentally, the future production forecast by this method is expected to include oil that might come from improved recovery of oil in place in fields already producing as well as oil that would come from future discoveries.

In broad terms all of these approaches attempt to provide estimates of oil and gas remaining to be discovered. But there is an important distinction among their objectives. Many of those estimating potential oil and gas resources have as their objective a single forecast of what has been called ultimate production. Such forecasts assume that the technologic, economic, or policy changes of the future will be merely a smooth predictable continuation of those that have taken place in the past. On the other hand, some have made an attempt to take account of possible substantive changes in economic and technologic conditions by reporting estimates of the total oil and gas originally in place, and then differentiating the presently economically producible reserves from the subeconomic resources that may be brought within economic reach in the future.

The National Petroleum Council estimates of 1973 and 1974 estimates of the Survey's resource appraisal group went some distance

in this direction but more along this line needs to be done to put estimates of potential resources into terms in which one can make some assessment of the effects of future technologic and economic developments that maybe markedly different from those of the past.

Coming back to the three approaches used in the estimates reported by the Academy's committee, each of them has strengths and weaknesses. The volumetric approach takes account of oil and gas that may be present in sedimentary layers and structures that have thus far not been recognized as containing petroleum. This approach may seem to some to imply that petroleum exploration geologists have not been very effective in pointing the drill towards the most favorable targets. This has not been the case, of course, for geologists and geophysicists have been effective for many decades now in guiding exploration.

One of my colleagues, however, has linked petroleum exploration to rabbit hunting, where the good hunter does not shoot until he sees what he thinks may be a rabbit. Coming into a new field, he may have some easy and obvious first shots, or he may go many days with no luck at all. Regardless of his initial success, it may take an experienced hunter some time to find all or even most of the rabbits in a given area. Moreover, if the hunter begins as a novice—and the petroleum industry began geologic exploration as a novice not too many decades ago—he may in the course of time learn to find rabbits in places he had not thought to look at the outset.

Senator JAVITS. Mr. McKelvey, I have an urgent phone call. Would you suspend for 2 minutes?

Mr. McKELVEY. Yes indeed [short pause].

Senator JAVITS. Would the witness please proceed. The Chair wishes to announce that Congressman Brown will take over the Chairmanship as I have to go somewhere else. You go right ahead.

Mr. McKELVEY. Thank you, sir.

This delayed success in rabbit hunting has many analogues in the form of significant petroleum discoveries in previously explored areas, and the volumetric method is a vulnerable means of giving some dimension to the potential of unexplored areas. The method is useful also in that with a minimum of detailed information it gives some idea of the potential resources of a given area and that is one of the reasons why it has been used by several Survey geologists, for we simply have not had detailed geological and geophysical information such as that collected by the oil industry, nor had we staff to analyze and interpret such data had they been available to us.

The principal disadvantage in the volumetric method is the one pointed out by the National Academy Committee, namely that the extrapolation from the explored to unexplored ground depends on some assumption as to how favorable the unexplored ground is compared to that already tested. The 1974 resource appraisal group estimates assume that the unexplored part on the average would range from half as favorable to just as favorable as the explored part. That assumption has been criticized as being too high, and those working on these estimates have listened carefully to these criticisms and are examining the evidence. Instead of using an average value for this ratio, it would be better to vary it in the

light of specific knowledge of local geology and exploration history, but that takes more detailed knowledge and expertise than has been available in the past.

In any case, the volumetric approach is likely to give higher estimates than those obtained by the other methods because it allows for presence of oil and gas in rocks in which no specific targets have been identified. While this is obviously a disadvantage if it is misinterpreted as an assurance of what will in fact be found, properly understood it is also an advantage for it tends to indicate the maximum that can be expected in a given area if unexplored rocks are nearly as prolific as those already explored.

Referring to the 1974 estimates, I believe that it is useful to know that the undiscovered presently recoverable oil and gas resources in this country, onshore and offshore, might be of the order of 200-400 billion barrels and 1,000 to 2,000 trillion cubic feet of gas, and conversely that it would be unreasonable to expect more on the basis of past experience and available information. The attempt to appraise undiscovered recoverable resources, of course, is no prediction as to what actually will be found and produced, as do estimates of ultimate production, but merely establishes the target for exploration. It is important to know how large this target could be under favorable circumstances.

In early 1974 the approach taken by Mobil had the great advantage of being a hardhead analysis of the potential amount that can be found on the basis of its interpretation of available information. I think it can be interpreted as an estimate of the oil and gas that a large and able company thinks can be found and produced economically on the basis of available information.

It is extremely valuable to know, it seems to me, that a large oil company recognizes a potential for about 90 billion barrels of undiscovered oil and natural gas liquids in the United States onshore and offshore and about 375 trillion cubic feet of natural gas. Because the play approach focuses on areas that are believed to be prospective and utilizes only concepts and exploration tools now available, it may tend to underestimate the total potential.

Whereas Mobil or any of the large American oil companies are highly competent, the knowledge of one is by no means equivalent to the knowledge of the entire industry. One of the great strengths of the American industry is that it is composed of many competitors, including a large number of independents, each of which develops some exploration ideas that the others haven't thought of or haven't thought worth pursuing. A pool of industry appraisals of prospective plays would probably lead to a somewhat higher estimate than that of a single company, although I would expect such a total would still be lower than an estimate based mainly on volume of unexplored sediments.

The projections of Mr. Hubbert have proven to be remarkably accurate over the last several years and this lends credence to the validity of his projections as to the magnitude of resources remaining to be found. Because Mr. Hubbert's estimates are in essence based on the product of human activities, which in turn are influenced by economics, technologic development, and public policies, I believe

that they are most useful in indicating what is likely to happen if things continue to go the way they have in the past. This also is useful to know, and there is great significance, in particular, in knowing that if declining trends in exploration, discovery, and production continue, there are still 72 billion barrels of recoverable oil and 540 trillion cubic feet of gas to be produced from the United States onshore and offshore beyond proved reserves.

Projections of this type, however, assume that the course of future petroleum exploration and production is an inexorable one, regardless of major modifications in economic conditions, technologic advance, or public policies.

As you know, for nearly 2 decades, exploratory drilling in the United States has been on the decline largely as a result of diminishing incentive for exploration. In part this was the result of the ready availability of low cost foreign oil, the good opportunities that existed for discovery in many virgin foreign areas, and the institution of Federal policies that limited prices, particularly those for natural gas, and that limited the availability of acreage available for exploration, particularly on the Outer Continental Shelf. These factors were bound to produce a decline in exploratory drilling; and while there were apparently not many listeners during that period, there were many speakers, including Mr. Hubbert, who foresaw the imminence of a decline in domestic production and who were concerned about the growing gap between domestic production and consumption.

Now the situation has changed. The new policies and economics are not yet entirely clear, but the incentives for increased domestic exploration and production have already improved and may improve still further. Already there has been a marked increase in the level of seismic exploration and exploratory drilling, up some 29 and 27 percent respectively in 1974 compared to the previous year. It is too early to judge the results of new discoveries, but this accelerated exploration is bound to result in discovery of more oil and gas than would have been found in this period if previous drilling trends had continued.

It is also too early to tell how much additional production may result from the renewal or continuation of production from marginal wells that might have been abandoned had low prices continued or how much additional oil is being added by the institution or enlargement of secondary and tertiary recovery projects that would not have been started a couple of years ago, but the increased activities reported in both of these areas indicate that higher prices are bringing about more production than would have been achieved before they took effect. The trends of the recent past, therefore, seem to be changing under the influence of economics, technology, and policy, as it seems reasonable to expect that they should.

From what I have said, Congressman Brown, I hope it is clear that we should not place great reliance on any single estimate of the magnitude of undiscovered resources—the unknown in a very real sense—but that there is value and meaning in all of the estimates available if one understands what each of them is trying to assess and how each one has been made. I know the committee is

interested in the significance of these estimates and the implications of the differences between them in the terms of policy.

With respect to that question, let me emphasize that all of the estimates lead to the same conclusion on three very important points. One is that significant amounts of oil and gas remain to be discovered and developed and that additional exploration and related research on the improvement of discovery and extractive methodology will be worthwhile.

Another is that the most promising prospect for the discovery of additional accumulations are in the frontier areas of the outer continental shelves and Alaska, for as pointed out on page 90 of the National Academy Committee's report, all of the estimates are in agreement on that point.

Third, even the highest estimates show that this country will soon need to shift to other sources of energy as the mainstay of its energy supplies, particularly if energy consumption continues to increase at rates similar to those prevailing in recent decades. Energy conservation and vigorous attempts to develop other sources of energy must be important objectives, regardless of which of the estimates should prove to be correct. This is true partly because the period separating the time at which production would begin its final decline under the lowest and highest estimates is only a couple of decades or so, and partly because of the long leadtime required to develop a new energy supply apparatus.

Speaking of the significance of these estimates in terms of policy, the Washington Post on February 12 quoted Mr. Skinner as saying that, "Project Independence has built into it some very high estimates of oil and gas reserves. If Project Independence depends on increasing oil production in the United States, then it's on very shaky ground." The National Academy's report itself stated that, "undiscovered resources of oil and natural gas are considerably smaller than that indicated by figures currently accepted within Government circles."

As a matter of fact, the Project Independence Oil Task Force projections were not based on the most optimistic resource estimates. I was the chairman of that task force and we recognize at the outset that it would be desirable to use estimates which would represent the widest possible consensus. We selected for this purpose the 1973 estimates of the National Petroleum Council, which were based on the work of a number of regional committees who were extremely well informed on regional prospects. Their estimates of undiscovered oil in place were 385 billion barrels, of which we assumed about one-third or 127 billion barrels would be recoverable under 1973 conditions. This is only 14 billion barrels more than the National Academy Committee's estimate of 113 billion barrels—a difference that I'm sure no one familiar with reserves and resource estimates would consider significant. The Project Independence Blueprint study also took into account proved reserves and identified deposits, such that estimates of combined reserves and undiscovered recoverable resources total 190 billion barrels.

The oil task force also made allowance for additional production from heavy crude oil deposits and tar sands and for some increased

recovery of the nearly 300 billion barrels remaining oil in place in known deposits. These resources were adequate, and more than adequate, to support the production projected through 1988, but the task force pointed out in its report that:

If production came into the range of 15 to 22 million barrels a day, estimated at higher prices in 1985-88, the limits of the United States resource base make it unlikely that production could be maintained at such levels for more than a few years.

Incidentally, I may point out that the National Academy Committee's estimate of 113 billion barrels of crude oil and natural gas liquids appears not to be an estimate in the sense of calculations made under specified assumptions. As the report states, it represents the judgment of the panel in the light of the several estimates available to it. The estimate is a middle ground figure and evidently reflects the committee's judgment that whereas the survey's resource appraisal group's estimates are too high, the Mobil and Hubbert estimates are somewhat too low.

Congressman Brown, permit me now to describe briefly work going on in this area in the Geological Survey. As I indicated earlier, for many years we were hampered in these studies by the lack of availability of data and personnel. During the last year or so we have been funded to purchase substantial industry data for an oil and gas data bank, and we also have acquired additional staff. We are building up information on the subsurface geology of the United States that will allow us to make better appraisals of the potential of specific areas. This information will be available to the public and we hope it will both improve our understanding of our resource potential and aid in identifying targets for exploration. This may be of value in particular to the independents.

Since September we have been conducting a detailed and documented effort to assess the onshore and offshore oil and gas resources of the United States at the request of the Federal Energy Administration. This project is utilizing far more geological and geophysical data than have been hitherto available to us. The results will be delivered to FEA this spring. We are also enlarging our efforts to improve the methodology for estimating undiscovered resources by each of the approaches I described earlier, and we are exploring several other methods, including probabilistic ones that show some promise for application to this problem.

In conclusion, Congressman, I wish to emphasize that it is not possible at this stage to say with certainty how much oil and gas remains to be discovered in this country without a massive drilling effort which would be extremely costly and probably would not be definitive. Another National Academy's Committee, one concerned with food supplies, recently concluded that it is not possible to eliminate uncertainty in man's future, and I think that is probably a valid observation in all its aspects. What is important is to attempt to foresee the difficulties that lie ahead and then choose and pursue the directions that promise to lead to acceptable solutions.

The estimates of undiscovered oil and gas resources in the United States all tell us that significant amounts of oil and gas remain to be found if we encourage exploration, particularly in frontier areas,

but that we must begin now to develop other forms of energy as our main source of supply. Examination of the extremely high levels of consumption that we have reached through exponential growth during the past several decades tells us also that we cannot expect to continue such growth very long. We need to improve our technologic and sociologic efficiency in the use of energy and taper off our rate of increase and consumption through adoption of conservation practices. To illustrate the impossibility of continuing exponential growth, I have pointed out in recent months that a billion years' supply of anything at the present rate of consumption would be exhausted in only 584 years if our consumption grew at a continuing 3-percent annual rate of increase. If we had, say, 300 to 500 billion barrels of producible oil, we would have 48 to 80 years of independence at present rates; but we would have only 27.5 to 36.8 years at the 1950-70 rate of increase in oil consumption of 4 percent per year. That tells volumes about the urgency of energy R. & D. and conservation.

That concludes my testimony, Congressman Brown. I will be glad to try to answer your questions.

Representative BROWN of Ohio [presiding]. Thank you very much, Mr. McKelvey.

I think the more orderly way for us to proceed at this point is to go ahead with the presentations of Mr. Emery, Mr. Moody, and Mr. Perry. And I would ask Mr. Emery to join us at the table and make his presentation. Is he here?

Mr. CARLSON. Would you like us to stay seated at the table, Congressman?

Representative BROWN of Ohio. As you will. I assume you can move. I think all the microphones are working, so the other gentlemen can join us and make their presentations. You can sit where you are, Mr. McKelvey, and the other two of you are free to get up and wander as you will until we have finished all of the presentations. Mr. Emery, do you have a written presentation?

#### **STATEMENT OF KENNETH EMERY, CHAIRMAN, PANEL ON ESTIMATION OF MINERAL RESERVES AND RESOURCES, NATIONAL ACADEMY OF SCIENCES**

Mr. EMERY. No, sir. I had to be out of the country all last week, but Chairman Humphrey said that chapter 5, an excerpt entitled "Resources of the Fossil Fuels," from the report of the Committee on Minerals Resources and the Environment could serve as my written testimony. It is here. I do not intend to read the entire report, but even before I start I would like to commend very highly the testimony which Mr. McKelvey just gave. I think this is a very fine presentation, and I think the National Academy Committee will disagree with this only in very minor detail.

I believe we ought to look and see what the intent of the COMRATE Committee was. The name means Committee for Resources and the Environment. Our main objective was to learn what we could about some of the major mineral resources of the world, compare their present rates of production with their proved reserves,

and with their undiscovered resources, and make some estimate about the enhancement of these resources by substitution, and to develop some idea of how the undiscovered resources and the proved reserves would be influenced by such things as prices, environment, politics.

One of the panels chose to investigate the question of fossil fuels, being primarily oil and gas, coal and oil shale. We tried as much as possible to use public estimates, published data. At the time we started in 1972 there was considerable criticism of the figures that were available, and the statements were being made that no information at all was available. This we did not believe, and so our report basically was a summary of the methods that have been described in the literature, and estimates derived from those methods. In no way was this committee set up to arbitrate between different estimates that had been made of undiscovered resources of oil and gas. Neither was this committee intended to serve as a judgment panel for the probable success of Project Independence.

Although our objective went far beyond the undiscovered resources, apparently the public press focused on our estimates of undiscovered resources, and most of that information is provided in table 1 of the NRC report.<sup>1</sup> In Mr. McKelvey's testimony he mentioned that three different methods were used. In reality five different methods have been used.

These methods are:

(a) Straight volumetric; (b) geological basin analysis; (c) probabilistic estimation engineering analysis; (d) analysis of historical production and discovery data; and (e) analysis of discovery index.

Now, the remarkable thing to me, and I think probably to you as well, is that these five different approaches have exhibited a great deal of ingenuity, and yet have provided estimates that are quite far from each other. The problem is a complex one. It is not simply that of estimating how much oil is in a given tank, so to speak. The estimate also involves the question of where that tank is. Not only is it necessary to find the tank, and to measure the amount of oil and gas in the tank, but also to have some idea of how efficient the method of extracting the oil and gas from the tank will be.

Now, in table 1,<sup>1</sup> the estimates cover a wide range. I will just read them. I might say first we used companies A, B, C, and D. The reason for using company data, even though it was not published, was that the companies have spent a great deal of effort—hundreds of man-years—in making the estimates, and in no way could this small committee remake those estimates with the small manpower and the small time that was available to us. And the companies preferred not to be known by name to avoid problems of antitrust. Company A had an estimate of about 22 billion tons of undiscovered, recoverable oil resources;<sup>2</sup> company B, 3 to 8; company C, 7; company D, 12 billion tons.

In addition, using quite a different method, largely volumetric, the Geological Survey had also made estimates which were higher. One of the estimates was about 10, but the others, are much higher. The

<sup>1</sup> See table 1, p. 21.

<sup>2</sup> One metric ton of oil equals circa 7.5 42-gallon barrels.



highest is 61, and another is at 27 to 54 billion tons. The committee recognized that these estimates are based on different methods than the estimates provided by the oil companies. From our point of view, we thought it advisable, as Mr. McKelvey pointed out, to accept more conservative estimates, thinking that most of the Geological Survey estimates are relatively high, and most of the oil company estimates are relatively conservative. Thus, we picked 15 billion tons.

And now if you turn to table 3,<sup>1</sup> the important thing is this: That the 1973 production of oil is 450 million tons, or to keep the thing in the same units, let us say approximately 0.5 billion tons.

Now, the proven reserves of crude oil are about 5 billion tons, roughly 10 times greater. We do not wish to say that this represents a future of only 10 years at the present rate of supply, because many things can happen. The undiscovered resources of crude oil are about three times greater than proven reserves, 15 billion tons. Our point here was that this is about 30 times greater than the present production; it does not mean 30 years supply, however, as the uncertainty may be on the order of plus or minus 50 percent.

In comparison let us look at the proved reserves of oil shale: Approximately 1,000 times the 1973 production of crude oil in the United States. The undiscovered resources of shale oil are six times greater. The committee is fully aware that there are problems in developing the oil from oil shale and that these problems have to be overcome. Nevertheless, the oil and gas potential in the oil shale and in the coal is perhaps three orders of magnitude greater than present annual production of oil. This contrasts with the very small amount, like 30 years, or 30 times present annual production, that would be present in the form of undiscovered conventional oil resources.

I think that covers the points which I wish to make beyond those which are shown in the report.

Representative BROWN of Ohio. Mr. Emery, thank you.

[The excerpt follows:]

[Excerpt from a report prepared by the Committee on Mineral Resources and the Environment (COMRATE), Commission on Natural Resources, National Research Council, National Academy of Sciences]

## MINERAL RESOURCES AND THE ENVIRONMENT

### CHAPTER V.—RESOURCES OF THE FOSSIL FUELS

#### INTRODUCTION

The subpanel on Fossil Fuel Resources examined estimates of United States and world resources of petroleum and natural gas, tar sands, oil shales, and coal.

An attempt has been made to standardize terminology throughout this study, following the simpler of the guidelines suggested by McKelvey (1972) and Theobald, Schweinfurth, and Duncan (1972). The term *reserves* is restricted to materials that can be extracted economically from deposits of known extent using conventional methods. The term *resources* is used for materials that occur in deposits that either have not yet been discovered (undiscovered reserves) or in deposits for which technology is not yet available (water too deep, or concentrations too low for economical recovery at present).

Accompanying the report are maps designed to show annual production, proved reserves, and undiscovered resources of fossil fuels within different large regions of the world so as to contrast areas of high production and areas of high consumption. Redistribution of resources mainly by ship, is evident.

<sup>1</sup> See table 3, p. 26.

Metric units are used throughout, but equivalents in English units are given in parentheses. For oil, one metric ton (tonne) is taken as equivalent to 7.5 barrels. Data are for the latest years available. For many maps separate data for 1971, 1972, and 1973 are included so as to present recent trends.

Estimation of resources of petroleum and natural gas is complicated by the fact that, while methods for the estimation of *proved reserves* are well established, there is no generally accepted method for estimating undiscovered resources. This is reflected in a considerable range in estimates of the latter, particularly estimates of U.S. onshore resources in the lower 48 states. Differences in estimates naturally lead to confusion over the availability of petroleum and natural gas from domestic sources. This panel has therefore paid particular attention to the methods used in arriving at various estimates. The matter is important because the size of known and discoverable resources sets limits on the ability of the U.S. to increase or even to maintain current levels of domestic petroleum production during the substantial period of time necessary for development of alternative sources of energy.

Data for reserves of petroleum and natural gas were taken as far as possible from published sources or compilations in order to avoid prejudice that might arise from use of unpublished compilations in company files. Most of the publications are articles in journals and bulletins written for industry. Government compilations might be considered unbiased by some readers, but they appear long after each year of interest. Only preliminary estimates are as yet available for 1973. When they do become available, the data are essentially the same as those of the technical journals. It is clear that an enormous quantity of public information is available on oil and gas production and reserves. It must be understood that the term *proved reserves* does *not* include all the hydrocarbons that are expected to be produced eventually from discovered oil and gas fields, but only that amount of hydrocarbon about which there is no question about recoverability. Published data around the world are not available on which to base an estimated amount of hydrocarbon discovered but not proved, so unpublished data have been used to estimate this category of reserves. But in the United States it is estimated that *discovered* fields will eventually produce an additional 50 percent over and above the cited "proved reserve."

A large amount of information is also available on domestic hydrocarbon resources in oil shale, and on resources in tar sands of Alberta. Information on resources in oil shales and tar sands elsewhere in the world is incomplete and sufficient only to indicate orders of magnitude of these resources.

Methods of estimating coal resources are well developed, involving standard methods of geological mapping and correlative investigations, together with sampling by conventional methods. Estimates of the United States resources of coal presented in the report are those calculated by the United States Geological Survey on the basis of data from industry, from the geological surveys of various coal-bearing states, and from its own investigations of U.S. coalfields. The estimates are based on a large body of information, and the order of magnitude of U.S. coal reserves and resources can be considered as well established. There is need, however, for much additional information on individual coalfields, and for information that will serve as a basis for estimates of reserves of coal of various types and qualities. Information on the sulfur content of coals in various fields is especially needed in view of the problems of sulfur pollution examined in Section III by the environmental panel.

Estimates of world resources of coal are likewise those calculated by the U.S. Geological Survey. Data for various continents are somewhat uneven in quality, but the orders of magnitude of resources in the world's major coal producing regions are probably well established at this time. It should be noted that data are for total resources of coal in the ground, roughly one-half of which is estimated to be recoverable.

## CONCLUSIONS

### *Petroleum and Natural Gas Resources*

1. World resources of petroleum and natural gas, discovered reserves and undiscovered recoverable resources, will be seriously depleted by the end of the century if present trends of world production and consumption continue.

2. An estimate of 15 billion tonnes (113 billion bbl) for United States undiscovered, recoverable resources of natural gas appears realistic.

3. An estimate of 15 trillion cu. meters (530 trillion cu. ft.) for U.S. undiscovered, recoverable resources of natural gas appears realistic.

4. A large increase in U.S. annual production of petroleum and natural gas is very unlikely.

5. The largest untapped oil resource, probably in excess of  $27 \times 10^9$  tonnes ( $202 \times 10^9$  bbl), is in the oil in known oil fields of the United States that is unrecoverable with present technology.

6. The second largest, but probably most accessible domestic oil and gas resource is under the continental shelves.

7. U.S. resources of petroleum in oil shale are extremely large, but future rates of production from this source are speculative.

#### Coal Resources

8. World and U.S. coal reserves plus resources are adequate for hundreds of years at current or even doubled rates of consumption.

#### RECOMMENDATIONS

We recommend:

1. *That in view of the long lead time required for development of alternative sources of energy, energy policy place a strong emphasis on conservation.*

2. *That research and development aimed at increasing recovery of petroleum from known oil fields be actively encouraged.*

3. *That there be speedy investigation of the continental shelves for oil and gas resources.*

#### OIL

##### *Production of Crude Oil and Natural Gas Liquids*

Data on annual production of crude oil in the United States and Canada are provided by the American Petroleum Institute in cooperation with the American Gas Association and the Canadian Petroleum Association (Anonymous, 1972a, 1973a). However, production data for the other nations of the world are assembled by the *Oil and Gas Journal* (Anonymous, 1973b, 1973d, 1974a) and they do not appear in government bureau reports until a year or more later, when they are published by the Bureau of Mines' International Petroleum Annual (Southard, 1973, 1974). When published, these data for foreign production are essentially the same as those given earlier by the *Oil and Gas Journal*. Two secondary sources are the International Petroleum Encyclopedia (McCaslin, 1973a, 1974a) that is edited and published by the *Oil and Gas Journal*, and the Minerals Yearbook that is published by the Bureau of Mines: the statistics in both compilations are essentially the same as the earlier published ones by the same organizations. Data on natural gas liquids (NGL) are more difficult to obtain, but the total for crude oil plus NGL production during 1971 was 553 million tonnes ( $41.5 \times 10^9$  bbl) (Albers et al., 1973, p. 1, 126, 127) versus 464 million tonnes ( $3.5 \times 10^9$  bbl) for crude oil alone in the United States. The tonnages of crude oil plus NGL for South America during 1971 were 240 versus 226 millions ( $1.8$  v.  $1.7 \times 10^9$  bbl). Information on NGL for most of the rest of the world is not reported, is included with the crude oil, or does not exist because the NGL was flared off with the natural gas. The world distribution of reported crude oil production alone is given by Figure 1 for 1971, 1972, and 1973; that for crude oil plus NGL is given by Figure 2. Annual production of crude oil alone (Figure 1) is concentrated in the Middle East, which during 1973 produced about 38 percent of the world total, followed by Asia (mainly U.S.S.R.) with 17.1 percent, followed by the United States with 16.7 percent. This was the first year that oil production in the United States has not exceeded that in Asia. In fact, Figure 1 depicts a steady decline in oil production during the three year period by the United States and a steady increase by both the Middle East and Asia.

##### *Annual Production of Crude Oil and Natural Gas Liquids from Offshore Fields*

Production of crude oil plus NGL from the continental shelf or other underwater regions during 1971 was tabulated by Albers, et al. (1973) who considered Lake Maracaibo (Venezuela) production to be from land rather than from underwater. Data for later production of crude plus NGL are lacking, so Figure 3 is based upon production of crude oil alone taken from the *Oil and Gas Journal* (McCaslin, 1972, 1973b). Unfortunately, the *Oil and Gas Journal* listings for crude oil production in underwater parts of other countries during 1972 and 1973 are only for giant offshore oil fields and not for all fields (the giant offshore fields contribute about 95 percent of the total offshore crude oil production). Thus the data for 1971 are not quite comparable with those for

the world during 1972 and 1973. The main trend observed in Figure 3 is a steady decrease in offshore production of crude oil from the continental shelves of the United States, in contrast with a slight increase in production from other underwater areas of the world, averaging about 18 percent of total production for the three years. Concentrations are in the Persian Gulf, Lake Maracaibo, Gulf of Mexico, Gulf of Guinea, southern California, Bass Strait (Australia), South China and Java seas, and the Caspian Sea in decreasing order of annual production.

#### *Annual Consumption*

Data on annual consumption of refined petroleum products were compiled and published for the various countries of the world by the World Petroleum Encyclopedia (McCaslin, 1973a, 1974a) and a year later by the Bureau of Mines' International Petroleum Annual (Southard, 1973, 1974). Data are not available from the Bureau of Mines for 1973. Data for individual Communist countries are not available for any years. Results from both sources are similar but not identical; therefore, in order to present comparable data for 1971, 1972 and 1973, Figure 4 is based entirely upon the World Petroleum Encyclopedia (McCaslin, 1973a, 1974a) that also contains the latest revised figures for consumption during the earlier two years. The regions of consumption of oil products (demand for refined oil) differ markedly from the regions of production (Figure 4 versus Figures 1 and 2). For example, the United States consumed about one-third more than it produced in terms of crude oil (increasing from 31 percent more in 1971 to 41 percent in 1972 to 47 percent in 1973), but Europe consumed about 21 times more than it produced. When production is expressed in terms of crude oil plus NGL the consumption for the United States during 1971 exceeded production by about 14 percent. Shipments to the United States and Europe came from most of the other regions, with the Middle East shipping 93 percent of its production. Consumption per capital ranged from 3.5 tonnes (26 bbl) for the United States to 0.1 tonne (0.75 bbl), for Africa, with the average for the world minus the United States and Europe at 0.3 tonne (2.25 bbl). Comparison of the data within Figure 4 shows that consumption increased 19 to 25 percent between 1971 and 1973 for Asia, South America, and Africa, but only 13 to 14 percent for the other regions including the United States and Europe.

#### *Cumulative Production*

Cumulative production of crude oil plus NGL was tabulated for 1971 by Albers, et al. (1973), but as no later data on NGL are available, the only way to have more up-to-date cumulative production figures is to base them upon crude oil alone. Accordingly, cumulative production in the different regions is taken from the only public source, the *Oil and Gas Journal* (Anonymous, 1973d), which as for previous years, cumulates to July 1 (Figure 5). As this compilation gives no data for cumulative crude oil production for the United States or for communist nations, data for these areas had to come from the American Gas Association (Anonymous, 1973a, p. 10) through 1972 for the United States and, from Albers, et al. (1973) for communist nations through 1971 (assuming that the communist nations produced little NGL). Both cumulations were updated to July 1, 1973 using annual production data from the International Petroleum Encyclopedia (McCaslin, 1974a). Noteworthy is the fact that the United States has produced more than one-third of the world's total crude oil produced to date. Comparison of the data in Figure 5 with those of Figure 1 shows little relationship between cumulative crude oil production and annual crude oil production. For example, the cumulative crude oil production for North America, Europe, and South America is 27 to 22 times 1973 production, whereas for Asia, Oceania, the Middle East and Africa it is only 13 to 7 times 1973 production. This lack of relationship is due to differences in the dates when initial large production began.

Cumulative offshore production of crude oil from the continental shelves and other underwater areas was tabulated by McCaslin (1974b) to the end of 1973. His tabulations to the end of 1971 were for total offshore crude oil (McCaslin, 1972), but those to the ends of 1972 and 1973 were only for giant oil fields. The best approximation seemed to be that of adding to the cumulative offshore inside-oil production through the end of 1971, the annual offshore productions for 1972 and 1973. The minor fields appear to add only about 5 percent to the world total for giant fields during 1972 and 1973, so the presentation in

Figure 6 is nearly correct. The ratio of cumulative total crude oil production to cumulative offshore crude oil production at the end of 1973 (Figures 5 and 6) ranges from 2.0 for South America (where production from Lake Maracaibo dominates) to 49 and 32 for Asia and Europe where offshore oil has been minor through 1973.

#### *Proved Reserves*

Total proved reserves of crude oil as of January 1, 1974, (Figure 7) are entirely from a compilation of data by the *Oil and Gas Journal* (Anonymous, 1973c). An earlier compilation, at the end of 1971, by Albers, et al (1973) of the United States Geological Survey, includes NGL for the United States and a few other nations, but omits it for most nations because they do not report NGL. Most of those that produce NGL include it with the crude oil. Comparison shows the results given on Figure 7 to be within 25 percent of the estimates by Albers, et al. and of two oil companies that provided records from their files; differences between these various sources are erratic as though due to unsystematic differences in methods of estimation from drillhole data in various regions. It is reiterated that estimates of proved reserves are smaller than the amount of oil expected to be produced ultimately from presently discovered fields. Comparison of Figures 7 and 1 shows little relationship of proved reserves to 1973 production of crude oil. The ratio ranges from 10 for the United States to 45 and 68 for the Middle East and Europe, with 31 as the world average. This ratio is not nearly as significant as popularly considered, because it is not a simple measure of how much oil remains to be produced. Instead, it is influenced considerably by the intensity of exploration, the dominant kinds of oil field traps and the price of the oil. Another ratio, that of crude oil reserves to 1973 annual consumption, also is of interest. This one ranges from only 3.2 for Europe (destined to increase with expanded exploration in the North Sea) and 5.6 for the United States to 183 for Africa and 650 for the Middle East. The ratio essentially is a measure of the number of years that proved reserves in a region can supply crude oil for the consumption in the same region, in the unlikely event that no oil is shipped, that no new reserves are found, and that consumption remains constant.

Offshore reserves of crude oil were tabulated by the *Oil and Gas Journal* (McCaslin, 1974b) to January 1, 1974, and these data are the basis for Figure 8. Comparison of Figures 7 and 8 shows that proved reserves of offshore crude oil in different regions range from 1.4 to 36 percent of total proved reserves in the same regions. The lowest percentage is for Asia (1.4) and Africa (7.6) and the highest is for Oceania (36.4). For the United States it is 19.6, which is slightly greater than the ratio of annual offshore to total annual crude oil production (Figures 1 and 3).

Weeks (1973) estimated the proved world offshore reserves of oil plus oil equivalent of gas ( $1000 \text{ m}^3$  of gas = 0.78 tonnes of oil or  $6,040 \text{ ft}^3 = 1 \text{ bbl}$ ) to be 19,000 million tonnes ( $143 \times 10^9 \text{ bbl}$ ). This figure differs considerably from the total of 13,000 million tonnes ( $98 \times 10^9 \text{ bbl}$ ) of crude oil from Figure 8 plus an estimated 700 million tonnes ( $5,250 \times 10^9 \text{ bbl}$ ) of oil equivalent from Figure 13, or a total of 13,700 million tonnes ( $103 \times 10^9 \text{ bbl}$ ) of oil plus oil equivalent.

#### *Total Discovered Reserves*

In addition to the proved reserves discussed above, there is a sizeable increment of reserves that have been discovered but are not considered to be "Proved." This increment, estimated to average 50 percent, is the difference between ultimate production actually obtainable from any given reservoir, and the proven reserves assigned to that reservoir at any given time.

The reserves shown on Figure 9 represent best estimates of the total amount of recoverable oil actually discovered, including both proved reserves and the increment discussed above. Since there are no published estimates of the discovered but unproven increment, estimates of Company D were used in compiling Figure 9. There is a sizeable amount of published information on the techniques of such reserve estimation; Company D's estimates were made using well known and widely accepted techniques.

#### *Gas*

Annual production of natural gas was compiled from data in the *Oil and Gas Journal* (Anonymous, 1972b, 1973b, 1974a) and shown in Figure 10 for the same regions as for crude oil production. The measurements are within about

25 percent of those compiled by Albers, et al. (1973) and those in unpublished files of Company D. Little change in gas production is exhibited for the three years 1971, 1972, and 1973 by the United States, North America, and South America. Gas production decreased for Africa, but it increased 50 percent for the Middle East, 37 percent for Europe, 33 percent for Oceania, and 17 percent for Asia. The distribution of the 1973 annual production of gas (Figure 10) is very different from that of oil (Figure 1). The ratio of gas to crude oil  $\text{m}^3/\text{tonne}$  ranges from 5,000  $\text{m}^3/\text{tonne}$  (23,500  $\text{ft}^3/\text{bbl}$ ) for Europe and 1,450  $\text{m}^3/\text{tonne}$  (6,800  $\text{ft}^3/\text{bbl}$ ) for the United States (and North America) to less than 100  $\text{m}^3/\text{tonne}$  (471  $\text{ft}^3/\text{bbl}$ ) for the Middle East, Africa, and Oceania. The ratio for the entire world is 500  $\text{m}^3/\text{tonne}$  (2,350  $\text{ft}^3/\text{bbl}$ ). The high ratios for the United States and Europe are due to the nearness of the gas-producing fields to industries that can use the gas. Low ratios elsewhere are due to the high cost of liquefying and shipping the gas to industrial centers. If the amount of gas brought to the surface has the same ratio throughout the world as the average for the United States actual production (1.45), then about 2,560 billion cubic meters ( $90 \times 10^9 \text{ ft}^3$ ) of gas is brought to the surface but not used. This is nearly twice the amount that is produced and used in the world. Some of this gas is pumped back underground in order to improve recovery of oil, but most of it is flared and wasted. On the other hand, about two-thirds of the gas produced in the United States is not associated with oil. Presumably, little such unassociated gas is produced elsewhere except in Europe or Japan, and so the amount of natural gas flared to waste is correspondingly reduced below the estimate above.

Partial confirmation of the waste of natural gas in undeveloped nations is provided by incomplete statistics on gas production, gas that is marketed, gas used in repressuring, and gas that is vented or flared. These data were assembled and published by the Bureau of Mines (Koelling, 1974). The statistics for 1972 were plotted in Figure 11 to permit comparison with data presented by the other figures. The totals are similar to those of Figure 10, but the similarity is taken as an indication that losses due to flaring are grossly underreported. Nevertheless, Figure 11 clearly shows a greater utilization of natural gas (or lesser wasting of it) in industrialized regions than in undeveloped ones. Expressed in another way, the United States, all of Europe, Canada, Australia, Japan, and New Zealand market 94 percent of their gas, whereas all other nations together market only 31 percent. In the United States and Canada 84 percent of the rest of the gas is used for repressuring, but in the rest of the world 80 percent of it is listed as flared, but probably this is a minimum percentage.

Offshore gas production was mapped (Figure 12) from data of Albers, et al. (1973) for 1971. No data for 1972 or 1973 were found in the literature. For 1971 the United States produced 62 percent of the total offshore natural gas while producing only 19 percent of the total offshore crude oil. This has resulted in a much greater cumulative production of natural gas in the United States as compared with other oil producing regions of the world (Figure 13). The principal areas where large amounts of gas are still being flared and wasted are the Middle East, North Africa and the Gulf of Guinea. But if plans presently in process in these areas are consummated, much of this waste will be stopped in the reasonably near future. Considerable but unknown quantities of NGL are flared off with the natural gas.

### *Proved Reserves*

Proved reserves for natural gas (Figure 14) are only 11 times 1973 production (Figure 10 for the United States, in comparison with 42 times for the entire world. The largest ratios of proved reserves to 1973 production are for Africa (530), Oceania (310), Middle East (220), and Asia (80). However, the high ratios in industrially undeveloped regions are simply the result of low annual reported production of gas (instead, pumping it back underground or flaring) where its use is impractical or where liquefying and shipping is too costly.

## UNDISCOVERED RECOVERABLE RESOURCES OF OIL AND GAS

### *United States*

Many estimates of undiscovered resources of oil or gas in the United States have been made during the past three decades by men associated either with oil companies or with the U.S. Geological Survey (McCulloh, 1973). Best known

are those of Weeks (1948, 1958 and 1960) formerly of Standard Oil Company of New Jersey (now Exxon Company) and now a consultant, and Hubbert (1956, 1959, 1962, 1966, 1967, 1969, 1971 and 1974) formerly of Shell Oil Company and now of the U.S. Geological Survey. Essentially, Weeks estimated the areas and volumes of sediment in major basins of the world and multiplied these by the concentrations of oil in similar basins arranged in three groups according to degrees of favorability for petroleum. His estimate of undiscovered crude oil plus natural gas liquids was 22,300 million tonnes ( $167 \times 10^9$  bbl) for land and ocean floor of the United States in 1960. In contrast, Hubbert (1967) based his estimates of undiscovered reserves of oil and gas of the United States upon statistical projections of past oil or gas production and of drilling experience. Using this method, Hubbert estimated, as of January 1, 1967, 3,200–8,500 million tonnes ( $24\text{--}64 \times 10^9$  bbl) of undiscovered oil plus NGL and 5,000–14,000 billion  $\text{m}^3$  ( $180\text{X}480 \times 10^{12}$   $\text{ft}^3$ ) of natural gas for land and ocean floor exclusive of Alaska.

Many large oil companies that have active research programs continuously compile information upon petroleum potential in new and old areas. Mostly, this information is considered proprietary, but some of it was provided by Company C (did not wish to be identified here), whose estimate in 1973 for recoverable crude oil plus NGL likely to be discovered in the United States between 1973 and 1985 is 7,300 million tonnes ( $55 \times 10^9$  bbl). Far more complete information was provided by Company D, which was highly cooperative in this study. Its estimates for the United States updated to April 15, 1974 are 11,900 million tonnes ( $89 \times 10^9$  bbl) of crude oil plus NGL, including 7,200 million ( $54 \times 10^9$ ) in offshore areas. For natural gas its estimates are 12,600 billion  $\text{m}^3$ , including 4,800 billion  $\text{m}^3$  ( $170 \times 10^{12}$   $\text{ft}^3$ ) in offshore areas. Another independent estimates of 12,000 million tonnes ( $90 \times 10^9$  bbl) was formulated by Company E as of 1974. Larger estimates of undiscovered recoverable natural gas for the United States were made by Rossinier, (1973): 33,000 billion  $\text{m}^3$  ( $1,164 \times 10^{12}$   $\text{ft}^3$ ) including 7,000 billion  $\text{m}^3$  ( $250 \times 10^{12}$   $\text{ft}^3$ ) from offshore fields.

The other group of estimates was made by men of the U.S. Geological Survey. First was Hendricks (1965) who extrapolated the production per unit area of drilled basins throughout the rest of the basins or to similar basins, and thereby developed an estimate of undiscovered resources of crude oil amounting to 54,000 million tonnes ( $301 \times 10^9$  bbl) and of natural gas amounting to 37,000 billion  $\text{m}^3$  ( $1,300 \times 10^{12}$   $\text{ft}^3$ ) in the United States as of January 1, 1962. Recently, Theobald, Schweinfurth, and Duncan (1972) of the U.S. Geological Survey made new estimates of undiscovered producible resources of the United States using an extension of the method of Hendricks (1965). Their estimate for crude oil plus NGL was 61,000 million tonnes ( $458 \times 10^9$  bbl) and for natural gas it was 56,000 billion  $\text{m}^3$  ( $1,980 \times 10^{12}$   $\text{ft}^3$ ). Separate computations indicated that 26,000 million tonnes ( $195 \times 10^9$  bbl) of the crude oil plus NGL and 24,000 billion  $\text{m}^3$  ( $850 \times 10^{12}$   $\text{ft}^3$ ) of the natural gas was from offshore areas. Several times as much oil and gas was reported present but in concentrations too small for recovery by present methods. Publication of these estimates aroused considerable opposition from men who had studied the question of petroleum resources because the Geological Survey figures are so much larger than other ones. In a Senate hearing, Hubbert (1974) pointed out that the estimates made by Zapp only SGS (1972) considered that the richest parts of the basins that were selected for drilling by oil companies were typical of the entire basins. In other words, the amount of oil to be produced, according to the U.S. Geological Survey, would be proportional only to the number of wells drilled, with no importance attached to differences in the geology within different parts of the basins. Actual drilling experience, however, shows that the oil produced per well in a given field or region decreases with the number of wells drilled, sometimes expressed also as barrels of oil discovered per foot of exploratory drilling.

A new set of estimates then was prepared by the U.S. Geological Survey (McKelvey, 1974) with lower figures attributed to consideration of newly available geophysical data. These estimates are 27 to  $54 \times 10^9$  tonnes ( $200\text{--}400 \times 10^9$  bbl) of crude oil plus NGL, including 8 to  $17 \times 10^9$  tonnes ( $64\text{--}128 \times 10^9$  bbl) in offshore areas. For natural gas the new results are 28 to  $57 \times 10^{12}$   $\text{m}^3$  ( $990\text{--}2,000 \times 10^{12}$   $\text{ft}^3$ ) including 11 to  $23 \times 10^{12}$   $\text{m}^3$  ( $390\text{--}810 \times 10^{12}$   $\text{ft}^3$ ) in offshore areas. The revised estimates are much lower than the ones of 1972, but they still are considerably higher than those made by other men and organizations.

Table 1 compares the estimates of undiscovered recoverable resources of crude oil plus NGL and of natural gas in the United States.

TABLE 1.—ESTIMATES OF UNDISCOVERED RECOVERABLE OIL RESOURCES OF THE UNITED STATES

	Oil and NGL		Gas	
	(10 <sup>9</sup> tonnes)	(10 <sup>9</sup> bbl)	(10 <sup>12</sup> m <sup>3</sup> )	(10 <sup>12</sup> ft <sup>3</sup> )
Oil companies:				
1. Company A (weeks, 1960).....	22.3	(168)		
2. (Hubbert, 1967).....	<sup>1</sup> 3.2-8.5	<sup>1</sup> (24-64)	<sup>1</sup> 5-14	<sup>1</sup> 180-500
3. Company C (1973).....	<sup>2</sup> 7.3	(55)		
4. Company D (1974).....	11.9	(89)	12.6	(450)
5. Company E.....	12	(90)		
U.S. Geological Survey:				
6. Hendricks (1965).....	46	(346)	37	(1,300)
7. Theobald, et al. (1972).....	61	(458)	56	(1,980)
8. Mickelvey (1974).....	27-54	(200-400)	28-57	(990-2,000)
9. Hubbert (1974).....	9.6	(72)	15.3	(540)

<sup>1</sup> Exclusive of Alaska.

<sup>2</sup> Estimated discoverable between 1973 and 1985.

The Panel's review of various estimates and consultations with various men and organizations involved indicate that five different methods of estimating undiscovered hydrocarbon resources have been employed: (a) straight volumetric, (b) geologic basin analysis, (c) probabilistic exploration/engineering analysis, (d) analysis of historical production and discovery data, and (e) analysis of discovery index. Method (a) was used in estimate 6. A combination of methods (a) and (b) was used in estimates 7 and 8. Method (b) was used in estimate 5. Methods (c), (d), and (e) were used in estimate 4. Methods (d) and (e) were used in estimates 2 and 9. Method (a) and the combination of methods (a) and (b) used by various members of the U.S. Geological Survey yielded results which appear high, whereas the estimates 2, 3, 4, 5, and 9 above, using methods (b), (c), (d), and (e) yielded reasonably consistent results.

A breakdown of estimate 4 furnished by Company 4, and a comparison with a breakdown of the 1974 Geological Survey estimate (see Appendix) indicates that most of the differences between estimate 8 and estimate 4 and 9 lie in resources estimated for the conterminous 48 states.

The estimates were reviewed by the panel with various men involved. In attempting to reconcile the differences between estimate 8 and estimates 2, 4, 5, and 9 it became evident that certain factors used in estimate 8 could have been more rigorously derived. Particularly critical is the discovery ratio assumed for unexplored parts of basins in making estimate 8 (see Appendix). The low figures for undiscovered resources were calculated on the basis of a discovery ratio of 0.5, the high figures on the basis of a ratio 1.0. Both ratios appear to be too high to be used in calculating undiscovered resources of the conterminous 48 states in which exploration has been carried on for more than 100 years. Hubbert (1974b) has rigorously appraised the value of the ratio based on drilling, discovery, and production data covering all explored basins in the conterminous United States. He found the value of the ratio, with a high degree of certainty, to be very near 0.1. When this ratio is applied to the portion of estimate 8 representing undiscovered resources in the conterminous 48 states, estimate 8 is reduced to 16 billion tonnes (approximately  $120 \times 10^9$  bbl).

Upon review of these several estimates and the methodologies upon which they are based, it is the judgment of the panel that the undiscovered hydrocarbon resource base of the United States including Alaska onshore and offshore, approximates 15 billion tonnes (113 billion bbl) of crude oil and NGL, and 15 trillion cubic meters ( $530 \times 10^{12}$  cubic feet) of gas. Although there is unavoidable uncertainty in these figures, the uncertainty is insignificant when viewed in the context of the enormous difference between the size of these resources and those of coal and of shale oil (see Table 3).

All estimates are in agreement that the bulk of undiscovered oil resources will be found either offshore or in Alaska. In both areas development will be slower and more costly than on-land development. Also, both terrains present added problems stemming from the need to consider the effects of oil production on relatively unknown or extremely delicate ecosystems.



## FUTURE RATES OF U.S. PETROLEUM PRODUCTION

The analyses by Hubbert (1956, 1957, 1959, 1962, 1966 and 1967, and Appendix) indicate there are definite mathematical relationships between ultimate reserves, changes in rates of discovery with time, changes in proved reserves with time, and rates of petroleum production. Given an ultimate reserve (production to date + proved resources + unknown recoverable resources) of around  $33 \times 10^9$  tonnes ( $247 \times 10^9$  bbl), a substantial increase in U.S. annual production of crude petroleum, even for a short period, is very unlikely. Given the long lead time necessary for development of alternate sources of energy, it seems evident that conservation of petroleum should receive a strong emphasis in U.S. mineral policy if dependence upon imports of petroleum is to be reduced.

## UNRECOVERED RESOURCES OF PETROLEUM IN KNOWN OIL FIELDS OF THE UNITED STATES

Oil produced in the United States plus proved reserves of oil are approximately  $18 \times 10^9$  tonnes ( $136 \times 10^9$  bbl). It is well known, however, that by use of present methods only a part of the total oil in place in known oil fields is recoverable by use of present technology. Percent of recovery varies widely from field to field, depending on the characteristics of the contained oil and the characteristics of the reserves. In a recent symposium on tertiary recovery methods (Snyder, 1974) a range from 13.5 to 46 percent was cited. A firm figure for the average recovery percentage for all oil fields of the United States is not available, but 30 percent appears reasonable, whereas 40 percent is probably too high. Even if the latter figure is accepted, however, it means that in known oil fields some  $27 \times 10^9$  tonnes ( $202 \times 10^9$  bbl) remains unrecoverable, roughly twice the estimated unknown recoverable resources. Known unrecovered oil thus appears to constitute the largest single untapped oil resource of the United States.

Research aimed at improving recovery percentages has been carried on for many years, and substantial improvements have been achieved since the earlier days of the petroleum industry. Primary recovery from ordinary wells has been supplemented with marked success by secondary methods of gas reprocessing and water flooding. It is generally agreed that further improvement by developing tertiary recovery methods will not be easy, but in view of the energy resources at stake, research and development of improved methods of recovery should be actively encouraged as a part of national mineral policy.

One means of increasing recovery from known fields is the mining of oil-rich sands from reservoir beds of oil fields where well have reached the point of uneconomic production. Where the sands are shallow enough, they can be mined by stripping, like shallow coal beds. According to Herkenhoff (1972) and Anonymous (1974b), there are 383 known shallow oil fields (overburden less than 150 meters [500 feet]) in the United States. If these were mined, the oil recovery might be increased from the usual 25 to 40 percent attained by wells to perhaps 90 percent. Similarly, if new techniques of tertiary recovery are developed, about twice as much additional oil might be produced as has come from past cumulative production, perhaps yielding 14,000 million tonnes ( $105 \times 10^9$  bbl) for the United States and 39,000 million tonnes ( $290 \times 10^9$  bbl) for the world (Figure 4).

## WORLD OIL RESOURCES

Estimates of undiscovered resources of oil and gas for the world have been compiled only by oil companies; material is available from Weeks (1960), from Company C for 1973, and from Company D for 1974. The estimates for crude oil plus NGL have been plotted together on Figure 15. The wide range of the estimates is expectable in view of differences in information available to each organization. Undiscovered resources of natural gas were estimated only by Company D, with results presented in Figure 16. Comparison in Figures 15, 7 and 1 shows that undiscovered resources of crude oil in the world exceed proved reserves and they are 25 to 75 times the 1973 production of crude oil. Similarly, Figures 16, 14 and 10 show that undiscovered resources of natural gas are about 100 times 1973 world production.

Published estimates of offshore undiscovered resources of the world have been made by Weeks (1973, 1974), who combined crude oil plus NGL with natural gas (using a ratio of  $1000 \text{ m}^3$  of gas equals 0.78 tonne of oil ( $6.040 \text{ ft}^3$  gas = 1 bbl oil)). His results for undiscovered total petroleum resources amount to 183,000 million tonnes (1,370 billion bbl) for the continental shelves,

small basin shelves, and shallow seas;  $61,000 \times 10^6$  tonnes (460 billion bbl) for the continental slopes;  $12,000 \times 10^6$  tonnes (90 billion bbl) for the continental rises; and  $3,500 \times 10^6$  tonnes (26 billion bbl) for deep-sea trenches and associated ridges. This total of 260,000 million tonnes ( $1,950 \times 10^6$  bbl) for undiscovered resources on the ocean floor approaches the 320,000 million tonnes ( $2,400 \times 10^6$  bbl) for Weeks' (1960) estimate for the crude oil plus NGL of the world plus the Company D's estimate of undiscovered natural gas of the world (Figure 16) converted to oil equivalent.

Soviet interest in undiscovered petroleum resources of the ocean floor is illustrated by publications on general geological factors (Fedynskiy and Levin 1970) as well as by quantitative estimates (Kalinko, 1969). The latter estimated 34,200 million tonnes (257 billion bbl) of oil and 13,444 billion  $m^3$  (475 trillion  $ft^3$ ) of gas beneath water-covered regions of the world; Soviet estimates are thus much lower than those of Weeks (Figures 15 and 16).

#### SPECULATIVE RESOURCES OF OIL AND GAS

The most spectacular petroleum accumulations are those in the giant oil and gas fields of the world. In fact, 70 percent of the past cumulative production plus proved reserves of oil and 50 percent of the same for gas is in the giant fields (Halbouty, et al., 1970). Probably an even higher percentage of offshore oil and gas is from giant fields, as the high costs there preclude development of small fields on the ocean floor. As shown by Figure 17, most of the giant fields occur in two broad curved belts, one in northern South America and western North America and the other in northern Africa, the Middle East, and the boundary between Europe and Asia. There and elsewhere the fields occur in clusters except in mainland China, where scattered single fields attest to incomplete exploration and an expectation of future substantial addition to production and reserves.

Oil and gas fields are widespread along many continental shelves (Figure 18). Noteworthy is their absence or rarity off eastern Asia, (except Indonesia) southern Asia, eastern Africa, northwestern Africa, eastern United States, eastern South America, western South America, northern North America and Asia, and off Antarctica even though many of these shelves appear to have high potential (Figure 19). Many of the gaps can be ascribed to climatically inhospitable regions; others are due to politically inhospitable host nations. As politics change, considerable filling of gaps in the distribution pattern of offshore oil fields may occur. Particularly promising are the ancient deltas of large rivers of the world (Figure 20). Many of these deltas are major producing areas of oil and gas. Most others are inadequately explored owing to difficulties of terrain or politics. When explored, these deltas should materially increase oil production and reserves.

Belts of thick marine sediments of Mesozoic and Tertiary age (Figure 21) contain fields that produce about 60 percent of the world's oil and gas. Most of these belts underlie coastal regions, where they have been localized by marginal troughs bounded on their oceanward sides by dams of tectonic, diapiric, or reefal origin (Emery, 1970). Because the sediments in these troughs are thick and contain much organic matter produced from nutrients in continental runoff, the quantity of oil and gas in them may well exceed the average for continental areas that are underlain by sediments. Again, most of the continental shelves of the world are less well explored than the land, so the concentrations of oil and gas beneath the shelves probably are greater than expected and listed among undiscovered reserves in Figure 15.

Lastly, nothing really is known about the oil and gas potential of the continental rises (Figure 22). The volume of sediments beneath these rises probably exceeds the total beneath the shelves. Much of the sediment is fine grained and some of it probably is rich in organic matter, having slid oceanward from positions of accumulation on the continental slope within the depth range of low oxygen content in the ocean water (Emery, 1969; and in press). Seismic-reflection records also show the presence of many velocity discontinuities, probably most of which are layers of sand distributed by turbidity currents, thus being potential reservoir beds. The same seismic records reveal the presence of numerous folds, faults, and stratigraphic traps, all of which could be sites for concentrations of oil and gas. In spite of the promise presented by continental rises, no exploratory drilling has occurred on them, largely because of the difficulty in controlling flows that might result from the drilling. Probably new methods of well completion on the deep-ocean floor will be developed

during the next decade or two, and these may be followed by testing of the oil and gas potential of the continental rises of the world.

#### SHALE OIL

Oil has been produced from oil shales in Scotland, China, Queensland, the East Baltic (Estonia-Leningrad), and South Africa, and production from the East Baltic area furnishes about 0.8 percent of the oil production of the U.S.S.R. Production in recent decades has never been, however, more than a small fraction of annual world oil production. In the United States oil has been produced only in experimental runs and one large pilot operation.

Data for the present report are drawn from reports by Duncan and Swanson (1965), Duncan (1967), Padula (1969), the National Petroleum Council (1972), and Culberson and Pitman (1973), and are summarized in Table 2. It must be stressed, however, that data even for the Green River oil shales, which have been more extensively explored and sampled than any other major shale oil deposits, are still incompletely tested. The figures in Table 2 serve only to indicate that United States and world resources of shale oil are very large, far larger than estimated total United States and world resources of conventional petroleum.

The sharp increase in prices of crude petroleum by the Organization of Petroleum Exporting Countries during 1973-74 has placed shale oil resources in an entirely new economic context. Marginal at best in 1972, some of the richer shale-oil deposits may now be economic. Tracts in the Green River oil shale basins have been leased, and mining and processing projects have been undertaken. Estimates of oil resources in the Green River formation differ considerably.

Duncan and Swanson estimated  $21.3 \times 10^9$  tonnes ( $160 \times 10^9$  bbl) of oil in shales of the Green River formation, averaging 10.5-12 wt. % of oil (30-35 gal./ton) of which half was considered recoverable under conditions of 1965. The National Petroleum Council (1972) estimated  $12 \times 10^9$  tonnes ( $90 \times 10^9$  bbl) to be worth present consideration, the remainder of the total of  $240 \times 10^9$  tonnes ( $1,800 \times 10^9$  bbl) in the formation being deeply buried, too low in grade, or insufficiently explored. Even this amount, however, is nearly equal to the estimated total of proved and undiscovered recoverable resources of conventional petroleum of the United States. Tracts leased by the Department of the Interior during the past year are considered to cover resources of not less than 340 million tonnes ( $2.6 \times 10^9$  bbl).<sup>1</sup>

The size of the resources of shale oil, both in the United States and in the world as a whole can easily arouse false hopes of their rapid development as an alternative to conventional petroleum as an energy source. There is little prospect, however, that shale-oil deposits can provide such an alternative. The problems involved in the shale-oil development are formidable, ranging from problems of mining and processing technology to environmental problems of disposal of waste and availability of water for processing. Capital investment required for production at a level of a billion barrels a year, roughly 15 percent of current U.S. annual consumption of petroleum, is enormous. At best, shale oil can be expected to serve only as a supplement to other sources of energy within the next 10 to 15 years.

#### TAR SANDS

The tar sands resources of the world are incompletely known, but it is already clear that they are major world resources of petroleum. The best known deposits, and by far the most productive, are the tar sands of Alberta, with a current production of about 2,200,000 tonnes ( $165 \times 10^6$  bbl) of crude oil per year. Total resources of oil in tar sands of three areas in Alberta have been estimated at around  $80 \times 10^9$  tonnes ( $600 \times 10^9$  bbl). Pow and others (1963) estimated  $40 \times 10^9$  tonnes ( $300 \times 10^9$  bbl) recoverable oil, whereas Humphrey (1973) estimates  $47 \times 10^9$  tonnes ( $350 \times 10^9$  bbl). New plants planned or proposed will greatly increase the scale of production. Large deposits of tar sand are also reported to occur on Melville Island in Arctic Canada.

United States resources of oil in tar sands are estimated at 3,900 million tonnes ( $29 \times 10^9$  bbl.). Tar sand deposits in eastern Venezuela (*Oil and Gas Journal*,

<sup>1</sup> During the past year, four tracts were leased, overlying a total of 3.6 billion tonnes (4 billion tons) of shale containing not less than 10.8% oil (30 gallons per ton), with a mean oil content of about 12.5% (35 gallons per ton). (Source: L. Schramm, USBM, by phone.)

1973) are reported to contain about  $93 \times 10^9$  tonnes ( $700 \times 10^9$  bbl) of oil, of which about one-tenth is considered recoverable with present technology.

Total world resources of tar sands are at present unknown.

TABLE 2.—SHALE-OIL RESOURCES

[In billions]

Area	Identified		Hypothetical		Grade	
	Tonnes	(Barrel)	Tonnes	(Barrel)	Weight percent oil	Gallon per ton
United States:						
Green River basins, Wyoming, Colorado, Utah.....	56	(418)	3.3	(25)	9-35	(25-100)
Do.....	190	(1,400)	80	(600)	3.5-8.8	(10-25)
Chattanooga shale, Mid-continent..	27	(200)	107	(800)	3.5-8.8	(10-25)
Alaska.....			33	(250)	3.5-8.8	(10-25)
Southwest Montana.....			0.7-1.3	(5-10)	3.5-5.2	(10-25)
Brazil:						
Southeast Brazil (Irati shallow)...	40-110	(300-800)	430	(3,200)	3.5-8.8	(10-25)
Southeast Brazil (tertiary).....	0.3	(2.0)			4-13	(11-37)
Scotland.....						
	0.04	(0.3-0.5)	Possibly >0.13	(>1.0)	5-14	(16-40)
Estonia-Russia: Southeast Baltic area..	1.3	(10)			18	(50)
Russia: North Siberia.....	10	(78)	470	(3,500)	8.8	(25)
					3.5-8.8	(10-25)
Yugoslavia:						
Morava Valley.....	0.03	(21)			8.8-14	(25-40)
Kolubara Valley.....				Large		
China: Various areas.....						
	1.9	(14)	19	(140)	5.2	(15)
Zaire:						
Stanleyville Basin.....	13.3	(100)			8.8	(25)
Mayumbe.....				Large		
South Africa: Karroo.....	0.02	0.130		Large	7-8.8	(20-25)
Australia:						
Port Curtis, Qsld.....	0.03	(200)			5.2	(15)
Various, N.S.W.....	0.03	(200)				

## COAL

The annual production of coal (Figure 25) is rather different from that of oil (Figure 1) and gas (Figure 10), although rather similar tonnages of coal and oil were produced in the United States as well as the entire world.

Asia and Europe were the dominant producing regions during 1971, with 40 to 37 percent of the total respectively, as compared with their 17 and 1.3 percent of the total world oil production. Only 0.3 percent of the world total of coal was produced in the Middle East as compared with its 38 percent of the world oil. About one-quarter of the coal was lignite and the rest was bituminous and anthracite.

Proved reserves and undiscovered resources of coal in the ground (Figure 25) are even larger than those for shale oil (Figures 23 and 24). Owing to losses in coal mining and processing, however, it is generally estimated that only one-half of the coal will be recoverable. Rather close confirmation of the government estimates for coal is provided by independent estimates from the files of Company D. Reserves and resources in the United States are about 5,800 times the annual production, and for the entire world they are about 5,000 times. There is, therefore, no cause for alarm about future needs for coal during the next hundred years. Moreover it, like oil shale, can augment the supplies of natural oil and gas, both as a fuel substitute and as material for distillation of oil and gas. About 110,000 million tonnes  $121,000 \times 10^6$  short tons) of reserves in the United States (200 times the annual production) are at depths shallow enough to be strippable, although one-third of this tonnage may require advanced machinery. Essentially 100 percent of the coal in place is obtained by stripping, but only about 50 percent is recovered by present underground mining methods.

If only half of the coal reserves and resources of Figure 26 is recovered, the amount of energy available from coal is still enormously greater than the total available from oil and gas. Reserves and resources are thus very large relative to United States needs; however, serious environmental problems must be resolved before these reserves can all become available. For the present, environmental problems set limits on the scale of using coal for energy.

#### COMPARISON OF ENERGY FROM FOSSIL FUELS WITH EARTH'S ENERGY FROM CERTAIN OTHER SOURCES

For ease in making comparisons, some of the more pertinent statistics were drawn from the preceding figures, rounded off, and compiled in Table 3. It is evident that the proved reserves of shale oil and coal are many times larger than those for petroleum, but this does not tell the whole story because of differences in heats of combustion.

TABLE 3.—COMPARISONS OF PRODUCTION AND RECOVERABLE RESERVES<sup>1</sup>

	United States	World
1973 production of oil.....	450×10 <sup>6</sup> Tonnes (3.4×10 <sup>9</sup> bbl)	2,700×10 <sup>6</sup> Tonnes (20×10 <sup>9</sup> bbl)
1971 production of NGL.....	80×10 <sup>6</sup> Tonnes (0.6×10 <sup>9</sup> bbl)	130×10 <sup>6</sup> Tonnes (10 <sup>9</sup> bbl)
1973 production of gas.....	0.65×10 <sup>12</sup> m <sup>3</sup> (23×10 <sup>12</sup> Ft <sup>3</sup> )	1.36×10 <sup>12</sup> m <sup>3</sup> (48×10 <sup>12</sup> Ft <sup>3</sup> )
1971 production of coal.....	0.51×10 <sup>9</sup> Tonnes (0.56×10 <sup>9</sup> Tons)	3×10 <sup>9</sup> Tonnes (3.3×10 <sup>9</sup> Tons)
Proved reserves of crude oil.....	5×10 <sup>9</sup> Tonnes (37.5×10 <sup>9</sup> bbl)	80×10 <sup>9</sup> Tonnes (600×10 <sup>9</sup> bbl)
Undiscovered resources of crude oil.....	15×10 <sup>9</sup> Tonnes (113×10 <sup>9</sup> bbl)	150×10 <sup>9</sup> Tonnes (1,130×10 <sup>9</sup> bbl)
Proved reserves of natural gas.....	7×10 <sup>12</sup> m <sup>3</sup> (250×10 <sup>12</sup> Ft <sup>3</sup> )	60×10 <sup>12</sup> m <sup>3</sup> (2,100×10 <sup>12</sup> Ft <sup>3</sup> )
Undiscovered resources of natural gas.....	15×10 <sup>12</sup> m <sup>3</sup> (530×10 <sup>12</sup> Ft <sup>3</sup> )	140×10 <sup>12</sup> m <sup>3</sup> (4,900×10 <sup>12</sup> Ft <sup>3</sup> )
Proved reserves of shale oil.....	0.5×10 <sup>12</sup> Tonnes (3.75×10 <sup>12</sup> bbl)	1.6×10 <sup>12</sup> Tonnes (12×10 <sup>12</sup> bbl)
Undiscovered resources of shale oil.....	3×10 <sup>12</sup> Tonnes (22.5×10 <sup>12</sup> bbl)	44×10 <sup>12</sup> Tonnes (330×10 <sup>12</sup> bbl)
Incomplete reserves of tar sand oil.....	4×10 <sup>9</sup> Tonnes (30×10 <sup>9</sup> bbl)	100×10 <sup>9</sup> Tonnes (750×10 <sup>9</sup> bbl)
Proved reserves and undiscovered resources of coal.....	3×10 <sup>12</sup> Tonnes (3.3×10 <sup>12</sup> Tons)	10×10 <sup>12</sup> Tonnes (11×10 <sup>12</sup> Tons)

<sup>1</sup> Numbers in this table are estimates of recoverable reserves and resources and are rounded off from the numbers given by the accompanying figures which have an unrealistic number of significant figures owing to their origin by addition of estimates.

TABLE 4.—ENERGY PRODUCED FROM FOSSIL FUELS COMPARED WITH EARTH'S ENERGY FROM CERTAIN OTHER SOURCES<sup>1</sup>

	10 <sup>20</sup> cal/year	(10 <sup>12</sup> watts)	10 <sup>20</sup> cal/year	(10 <sup>12</sup> watts)
Combustion by man:				
Crude oil and NGL.....	0.31	(4.1)		
Natural gas.....	.12	(1.6)		
Coal.....	.21	(2.8)		
Total.....			0.6	(8.0)
Dissipated by tides:				
(Earth, water, air).....			.2	(2.7)
Radioactivity of Earth (if like chondrite).....			2.5	(33.0)
Geothermal losses of Earth.....			3.2	(42.0)
Solar energy at Earth's surface.....			6,500	(76,000)

<sup>1</sup> Partly from Williams and Von Herzen (1974).

The average heats of combustion of oil (plus NGL), gas, and coal were taken as 11 Kcal/g ( $5.8 \times 10^6$  BTU/bbl) 9 Kcal/liter (1,260 BTU/ft<sup>3</sup>), and 7 Kcal/g (12,600 BTU/lb), respectively. Multiplying these numbers by the latest data on world production (Figures 2, 10 and 25), we find that the heats produced by combustion are within a factor of 3 for these materials (Table 4). They would be more nearly equal were much of the gas used rather than being returned underground or flared, as its heat value is about  $0.23 \times 10^{20}$  cal/year ( $0.09 \times 10^{18}$  BTU/year). The sum of the heat energy from the fossil fuels actually used is  $0.6 \times 10^{20}$  cal/year ( $6.25 \times 10^{18}$  BTU/year); this is three times the energy of the tides, and about one-fifth the energy of the Earth's interior produced by radioactive decay and manifested by geothermal gradients. However, it is only 0.01 percent of the solar energy; in fact, it equals only 48 minutes of solar radiation striking the entire Earth. Even the total reserves (including undis-

covered ones) have energy equal only to two days of solar radiation on the Earth. The unwary reader might conclude that solar energy offers a free ride with respect to supplies of oil, gas, and coal. However, in order to match the rate of fossil energy use, all of the sun's energy that reaches the Earth's surface within an area of 100 by 100 km near the equator would have to be captured. Moreover, at present solar energy is much less efficiently converted to electricity than is fossil fuel energy.

All in all, the low concentration of energy from the sun, the tides, and from the Earth's interior makes them unattractive at present as large scale energy sources compared with fossil fuels. Although natural oil and gas have limited lives at the presently increasing rates of use, the reserves of shale oil, tar sands, and coal are so great that fossil energy is likely to be available for several centuries to come. Their use, however, involves environmental costs: consumption of water, pollution of streams, and use of land areas for dumping of slag. These costs cannot be precisely evaluated against the value of the energy that is produced, owing to changing standards of public concern for environment versus energy.

Mr. BROWN of Ohio. Mr. Moody, I think we will turn to you next, please.

#### **STATEMENT OF JOHN D. MOODY, MEMBER, PANEL ON ESTIMATION OF MINERAL RESERVES AND RESOURCES, NATIONAL ACADEMY OF SCIENCES**

Mr. MOODY. Thank you, sir. I have a very brief oral statement to make.

I would agree wholeheartedly with what Mr. Carlson and Mr. McKelvey said initially, that the important thing really is for your committee and other congressional committees to appreciate the uncertainty of estimates of this kind that are being discussed here. We have no real way of seeing under the ground, and all of these estimates are subjective at least to some extent, and there is no way of getting away from that. And the only recourse, as Mr. Carlson said, is to drill a lot of wells, so that anything that can be done to encourage the drilling of holes in the ground will improve our estimates of undiscovered resources.

The National Academy Committee's estimate of 15 billion tons was a judgmental consensus of estimates available to the panel, and this was converted to 113 billion barrels through a conversion factor, and this lends an unwarranted appearance of accuracy to the number. You would think well, 110 to 115 billion; why 113? But actually the estimate was 15 billion tons, and that certainly should be expressed as a range and not as a single value. And the uncertainty in these things is well known; it is conceivable that the lowest estimate is too high and that the highest estimate is too low. Policy decisions are going to have to be made with these unresolved uncertainties.

I would like to point out that the deliberations of the panel took some two-and-a-half years. There were about six men involved in the panel work, although three of us did most of the work. And we examined a lot of things, and certainly it was not a one-day program.

The important conclusions that are to be derived from the work of the National Academy Committee are certainly in accord with those which Mr. McKelvey and Mr. Carlson indicated, and that is the

urgent need for more exploration, the urgent need for conservation and efficiency in energy matters—and all natural resources for that matter—and the urgent need for development of alternative sources of energy. Thank you.

Chairman HUMPHREY [presiding]. Let me publicly apologize to you gentlemen this morning. We thought we were going to have a very limited session at the Banking Committee, but we have had an extensive one as you can see. I finally just had to beg off.

Go ahead, Congressman Brown.

Representative BROWN of Ohio. Mr. Chairman, we have heard from Mr. Carlson and Mr. McKelvey, and we heard from Mr. Emery. Mr. Moody, have you completed your statement?

Mr. MOODY. Yes, sir.

Representative BROWN of Ohio. We will now hear from Mr. Perry if that is all right, Mr. Chairman, and then I thought we could ask questions when they are all completed.

Chairman HUMPHREY. Yes; very good.

### STATEMENT OF HARRY PERRY, CONSULTANT

Mr. PERRY. Mr. Chairman and members of the committee:

My name is Harry Perry. I am a consultant on energy matters and am appearing at this hearing at the request of the committee. My testimony was developed in my capacity as consultant to Resources for the Future, but does not necessarily represent the views of that organization.

I was extremely pleased to learn that the committee decided to hold hearings on the recently issued National Academy of Sciences report entitled "Mineral Resources and the Environment." It is only rarely that an Academy report receives the attention that this one was given—being highlighted on the front pages of the New York Times and Washington Post as well as by other papers. Unfortunately, most of the attention was directed toward the oil and gas resource estimates that were included in the report, and this section contained very little information that was not previously available. Except for some oil and a few gas resource estimates made by some unidentified oil companies in some unidentified way, all of the other data had been previously published.

The basis of the new oil company estimates are given in only the broadest terms so one cannot determine if they are based on new and presumably better data, on an improved methodology for making such estimates, or both. In short, this report does no more than add a few new estimates of total remaining oil and gas resources to a lengthy list of earlier estimates that are in the literature; nor does the published report permit the reader to judge the quality of these new estimates.

Based on this section of the report only one new conclusion is possible: At least a few of the oil companies are no longer as optimistic as the industry in general has been about the size of the future producible oil and gas resources of the United States. In short, at least for the four oil companies that participated, there was a movement away from the high estimates of the oil industry—and

the even higher estimates of the U.S. Geological Survey—toward the much lower estimates of Mr. King Hubbert, also associated with the Geological Survey. However, since only relatively few companies were involved, it is difficult to know if this opinion about the remaining recoverable oil and gas resources is typical of the views of the oil and gas industry as a whole.

The Academy report would have been much more useful had it examined in depth the different methodologies that have been used to estimate these resources, and tried to reconcile them, if that were possible. Even if a reconciliation were not possible, a detailed study and critique of the different methodologies and an explanation of why they lead to such a wide range of estimates would have been more useful than adding a few new, unexplained and uncheckable estimates to the literature.

While the daily press squeezed the report's findings into nothing more than another "U.S.-running-out-of-oil-and-gas" scare, the inaccurate reporting will have served a very useful purpose if it brings to the attention of this committee and other policymakers that there are large differences of opinion among experts in the estimates of how much oil and gas remains yet to be found.

Chairman HUMPHREY. I hesitate to interrupt here, but that issue is one that has bothered me so much. What methodology do you use? I do not think that is explained, Mr. Perry. Which one are you recommending for estimates?

Mr. PERRY. As you will see, Mr. Chairman, I will come up with recommendations that we have to go back to the drawing board and try to reconcile these methods.

Chairman HUMPHREY. Go ahead.

Mr. PERRY. You may well ask at this point why it is so important to know which of these estimates is correct.

To be sure, no matter which of the resource estimates will someday turn out to have been accurate there is currently very little time in which to switch to alternative fuels that are in ample supply in order for the Nation to achieve a position of reduced vulnerability to another embargo of our oil imports or to other supply interference. However, if the lower estimates of oil and gas resources yet to be found are correct then the prospect for a greatly increased or even a sustained output level of domestic oil and gas is poor and we must shift to other resources of domestic fuels that are in ample supply without delay and make plans for phasing them in at a rapid rate as permanent replacement of oil and gas resources.

On the other hand, if the higher resource estimates for oil and gas are right they imply a somewhat greater continued reliance on them, allowing us to make a more orderly transition to other domestic energy sources. Moreover, our attitude toward the future level of oil imports will probably vary according to our expectations of recoverable domestic resources, at least in the short run. In any event, of course, reduced fuel use per unit of GNP would be desirable, as the Academy report recommends, if it can be achieved without seriously weakening the state of the economy.

For the longer run—the next 30 to 40 years—the direction of energy policy is likely to be the same no matter whether the higher or



lower estimates of oil or gas resources are correct. By that time, the Nation will have had to shift away in large measure from these energy sources to other more plentiful ones. This will be so almost no matter how favorable the oil and gas supply function will turn out to be and under almost any reasonable assumptions about reduced energy use per unit of GNP.

Let me put on record some of the policy implications of the two different resource estimates. First, if the lower estimates are believed to be accurate it is imperative, as the Academy's report recommends, that a massive conservation effort be initiated. In fact, in the short run, for either the low or high resource estimate, conservation in some form is mandatory if we are to achieve a reasonable degree of security, since developing new energy supplies requires considerable time. Reducing consumption would extend the life of what appears to be relatively limited resources apart from reducing the many environmental problems associated with energy use. But reducing consumption too rapidly could cause severe and unacceptable economic dislocations. For example, the proposal by the President to reduce oil imports by 1 million barrels per day by the end of 1975 would have adverse economic effects that would probably not be worth the benefits—unless alternative usable resources are immediately available to replace the million barrels per day of imported oil. If we are to reduce security risks while at the same time reducing energy use, the Nation must move as rapidly as possible to develop a stockpile of oil resources that could be used in the event of renewed supply interruptions.

Second, if the lower resource estimates for oil and gas are believed to be correct, there would be little use in letting the price of oil rise or deregulating natural gas prices. Only relatively small quantities of these resources, small in the perspective of total energy consumption would be developed even at the higher prices and it would not be prudent to let the price of oil and gas rise merely to develop small increments of supply. A better strategy would be to concentrate on bringing on domestic energy sources that are in plentiful supply, such as coal and oil shale, which was just referred to, and to develop as rapidly as possible the use of new resources such as solar and geothermal energy. Since in any event these resources will need to be used to satisfy the Nation's energy supplies over the long run, we would merely speed up the start.

Third, in addition to developing new resources to replace oil and gas, methods must be aggressively pursued to recover a much larger share of the 200 billion barrels or more of discovered, but as yet unrecoverable, oil. There must be similar efforts to find means to produce the nearly 250 trillion cubic feet of natural gas from known sources that are too tightly bound in the geologic formations to be recovered at current gas prices.

These are very important potential deposits for recovery. For one thing, their location is known; moreover, the amounts are very large: In the case of oil, five times present proved reserves and in the case of natural gas, equal to the amount of gas in the proved reserves category.

To recover this oil will require a massive expansion in the use of secondary and tertiary recovery methods, some of which still must

be developed if they are to be successfully applied to oil reservoirs of various types. Similarly, to recover the tightly bound gas new methods still need to be developed, such as hydraulic, chemical or nuclear fracturing, to get the gas to flow at economically recoverable rates.

Fourth, the frontier areas in which new oil and gas are expected to be found must be exploited as early as possible and this will require accelerated leasing of the federally owned Outer Continental Shelf in the Atlantic and the Gulf of Mexico. Also, many of the very large deposits of low-sulfur coals found in the Western States are also in Federal hands, and leasing of these lands must also be accelerated, as must establishment of the associated provisions to protect the environment in which they exist.

Fifth, if the high resource estimates of oil and gas are believed to be correct, the same steps as outlined previously would be pursued but at a more leisurely pace and at lower costs. Conservation efforts could be less restrictive and the rate at which other resources would have to be developed, presumably at much higher than current prices, could be greatly reduced. The plentiful coal and oil shale resources could be developed at a much slower pace, probably at lower costs and certainly with reduced environmental consequences. There would also be more time to determine the amount of uranium resources that might become available at different prices. If the uranium resources are judged to be limited, an early decision will have to be reached on whether to stockpile foreign uranium oxide imports or to accelerate alternatively the development of the breeder reactor.

In either case—whether the oil and gas resource estimates are persuasively demonstrated to be high or low—a policy favoring greater self-sufficiency appears to be linked to higher future energy costs, barring unexpected technologic breakthroughs in finding and producing the required fuel forms. With the longer development time that the higher oil and gas resource estimates would allow it may be presumed that these could be developed at lower costs.

For these reasons it would be very desirable to know which of the estimates for oil and gas remaining to be found—that now differ roughly by a factor of two or more—are correct, or at least what probabilities are attached to them. Unfortunately, the Academy report is of little, if any, help in answering this question which, as I have attempted to show, is so critical for short-term energy policy decisions. A questionnaire recently distributed to producers by the Federal Energy Administration, as required under the law that established that agency, will certainly not provide answers to this question and very probably only add to the existing confusion.

In the face of this situation, Resources for the Future is planning to bring together in the near future those who have either published the various oil and gas estimates that vary so widely of possess the knowledge to analyze them critically. At the meeting the differences between the estimates, and especially the differences in methodologies, would be discussed in depth. We have no expectation that a single value for each of the resources will be agreed upon, but it may be possible to narrow the differences among them and decide which are more or less probable. This could only be accomplished by a critical

evaluation and comparison of the methods that were used. Even if this difference in estimates can be narrowed, a gap will probably remain. It is hoped that a better understanding of the precise reasons why that gap exists will be arrived at, not just by those who have made the estimates but also by those who are faced with making policy decisions based on this information and by a widening segment of the public who are interested in the problem.

It is hoped that such a meeting will also produce the identification of the research which will be required to obtain better agreement on a true value. If even this more limited objective proves impossible to achieve, then policymakers may have to accommodate to whatever uncertainty remains. But this in itself will be valuable since policies made on the basis of known and persistent uncertainties could be different than those made if the uncertainties are still thought to be resolvable.

In conclusion, it is my view that the Academy's report made a very modest contribution in bringing about more credible estimates of the remaining amounts of oil and gas that are yet to be produced. However, if that work directs the attention of policymakers to the great importance of resolving this problem, the group could have made a major contribution in leading toward the awareness that either better methods should be developed for getting more precise information or, alternatively, that energy policy decisions will have to be made in the context of unresolved uncertainty in the resource data base.

Chairman HUMPHREY. Mr. Perry, we thank you very much.

Also, I have a letter dated December 4 answering questions that we had posed to Mr. John Sawhill about potential reserves and production of oil in the United States. The answers are drawn from the Project Independence blueprint and provide an interesting background for today's discussion. I believe it would be appropriate, therefore, to have this letter included in the record. This is a letter to me dated December 4, 1974, from Mr. John Sawhill along with the questions that I posed to him for response to this committee.

[The letter, together with response to written questions posed by Chairman Humphrey follow:]

FEDERAL ENERGY ADMINISTRATION,  
Washington, D.C., December 4, 1974.

HON. HUBERT H. HUMPHREY,  
Chairman, Subcommittee on Consumer Economics, Joint Economic Committee,  
Washington, D.C.

DEAR MR. CHAIRMAN: I am enclosing answers to the questions which accompanied your letter of October 21, 1974. All of the questions you raise are very pertinent to our policies for crude oil pricing as they relate to incentives for further exploration and development of domestic crude oil reserves.

We have drawn upon the extensive work done in Project Independence to compile the best information we now have available. You are no doubt as aware as we are of the continuing changes in cost factors and their impact upon the economic feasibility of energy projects. In particular, the projects contemplated for shale oil production in the near term future have recently either been greatly scaled down or postponed indefinitely. Similarly, costs for recovering offshore and Alaska North Slope oil are constantly increasing. For these reasons, estimates of future production levels based on our current knowledge of costs are subject to a high degree of uncertainty. There is also much uncertainty about the volume and quality of yet to be discovered oil which makes up a substantial amount of the future supplies and prices estimated in the Project Independence

Report. These future supplies are particularly uncertain because the oil is expected to come from virgin oil provinces and from not yet fully proved tertiary recovery technologies.

With respect to the long run crude oil supply curve information you ask for, we are making use of the information contained in the Project Independence Interagency Oil Task Force Report. This information is based on the joint cooperative effort of professionals from government agencies which have interests in various aspects of crude oil production. Similarly, we have drawn upon the Shale Oil and Synthetic Fuels Task Force Reports for the crude oil supply curves from these sources. The question related to the long run supply curve for crude oil and its near substitutes from shale and coal is extremely complicated to answer. The factors which enter into the production of oil as well as the incentives and the capital needed for exploration to find new resources are diffuse and difficult to measure.

We are attempting to provide as broad an answer as possible given the wide range of assumptions which can be made about meaningful production functions and the efforts of varying prices on supply in the future.

We would be happy to discuss the information furnished with you or your staff and to furnish any additional information we may have if this is not sufficient for your subcommittee's work.

Sincerely,

JOHN C. SAWHILL,  
*Administrator.*

Enclosure.

RESPONSE OF HON. JOHN C. SAWHILL TO WRITTEN QUESTIONS POSED BY  
CHAIRMAN HUMPHREY

*Question 1.* What is the long run crude oil supply curve, excluding oil shale, synthetic fuels, and tar sands?

*Answer.* The Interagency Oil Task Force for the Project Independence Report derived a series of estimates for regional and national oil production based on a number of assumptions considered realistic. These estimates assume crude oil prices of \$4, \$7, and \$11 per barrel and are carried out for a 15 year time horizon. The estimates are made for two scenarios, a business-as-usual (BAU) situation and an accelerated development (AD) program. The first scenario assumes that industry will develop according to prevailing market conditions which are highly dependent on the cost of imported and domestic crude oil and future leasing rate offshore planned before the oil embargo. The second program assumes similar market conditions but further assumes rapidly expanded offshore leasing opening up the Naval Petroleum Reserves and a more optimistic tertiary recovery technology. Based on these estimates, as depicted in Table 1a, the following conclusions have been derived by the Oil Task Force:

1. Because of the long lead times required to bring new petroleum production on stream, domestic production will continue to decline for the next few years regardless of higher prices or policy changes designed to encourage exploration. At minimum acceptable prices of \$4 a barrel or less, national production would continue to decline under BAU assumptions. Only in the California, Gulf of Mexico, and Atlantic OCS regions would production expand at \$4 minimum acceptable prices.

2. At minimum acceptable prices of about \$7 to \$11 a barrel under BAU assumptions, production would increase by 1980 to 11.0 to 12.2 million barrels a day respectively, and by 1985 to 11.6 to 15.0 million barrels a day, exceeding the all time high production of 11.3 million barrels a day reached in 1970. At such prices, production in all regions would increase, but the major sources of new crude oil (excluding Natural Gas Liquids) in 1988 in excess of 1974 production under BAU assumptions at \$11 per barrel would include:

	<i>Barrels per day</i>
Secondary production onshore-----	2, 800, 000
Tertiary production onshore-----	2, 650, 000
Alaskan North Slope (Prudhoe Bay)-----	2, 329, 000
Gulf of Mexico OCS-----	981, 000
Southern Alaska OCS-----	520, 000
California OCS-----	668, 000
Heavy crude oil and tar sands-----	440, 000

3. Under AD assumptions (critical in which are the assumptions that OCS leasing would be accelerated, that Naval Petroleum Reserve No. 4 would be opened for development and would be highly productive, and that natural gas prices would be deregulated or at least regulated in an extremely enlightened manner), and at minimum acceptable prices of \$7 to \$11 a barrel, production in 1980 would be 12.7 to 13.4 million barrels a day respectively, and in 1985, 16.3 to 19.9 million barrels a day, a range within which falls the 1974 consumption level of about 17 million barrels a day. The effect of gas deregulation would be to lower minimum acceptable prices about \$1 a barrel.

The major sources of further increase from Accelerated Development in production of crude oil in 1988 over the BAU case would include:

	<i>Barrels per day</i>
Alaska North Slope (NPR No. 4)-----	2, 000, 000
Tertiary recovery onshore-----	840, 000
California OCS-----	800, 000
Atlantic OCS-----	610, 000
Heavy crude oil and tar sands-----	590, 000
Southern Alaska OCS-----	500, 000

4. If production came into the range of 15 to 22 million barrels a day, estimated as possible at high prices in 1985-1988, the limits of the U.S. resource base make it unlikely that production could be maintained at such levels for more than a few years.

The last conclusion arises from consideration of cumulative production compared to proved and potential reserves.

At a minimum acceptable price of \$7 a barrel under the BAU scenario, an estimated 49.5 billion barrels of petroleum liquids would be produced from 1974 through 1988. This is about equivalent to 48 billion barrels of proved and indicated additional reserves of oil and natural gas liquids reported at the end of 1973 by the American Petroleum Institute and the American Gas Association. However, under AD conditions at a price of \$11 a barrel, cumulative production between 1974 and 1988 would be 73.2 billion barrels. Assuming that reserves in 1988 would equal ten times the then current production rate, 92 billion barrels of producible crude oil and natural gas liquids would have to be added as reserves between now and 1988. About 78 billion barrels of this total would be crude oil. This is equivalent to 20 percent of NPC's estimate of undiscoverable crude oil, and is substantially greater than the most conservative estimates of undiscovered recoverable oil in the United States. (Oil Task Force Report pp. IV 5-6).

TABLE 1a.—SUMMATION OF UNCONSTRAINED PRODUCTION POSSIBILITIES FOR OIL AND NATURAL GAS LIQUIDS (INCLUDING ALASKA)

[Thousand barrels per day]					
Minimum acceptable price per barrel <sup>1</sup>	1974	1977	1980	1985	1988
<b>Business-as-usual:</b>					
\$4	10, 488	9, 048	9, 889	9, 718	9, 339
7	10, 488	9, 528	10, 661	10, 928	11, 056
11	10, 488	9, 867	12, 136	14, 716	15, 921
<b>Accelerated development:</b>					
\$4	10, 533	9, 658	10, 860	11, 502	11, 334
7	10, 533	10, 244	12, 408	13, 684	14, 274
11	10, 533	10, 275	13, 346	19, 491	21, 385

<sup>1</sup> Includes exploration and production costs at regional wellheads plus royalty and 10 percent DCF on investment but excludes lease acquisition costs and rentals.

Source: Oil task force report, page IV-2.

**Question 2.** What is the long run crude oil supply curve including shale oil, synthetic fuel and tar sands?

**Answer.** The long run supply curve has been predicted for shale oil, coal liquefaction and gasification, and tar sands. These prognostications have been

developed based on crude oil prices of \$4, \$7, and \$11 per barrel. Several different scenarios have been developed at each of these prices. The first two scenarios are the same as those described for crude oil development, business-as-usual and accelerated development. However, the business-as-usual situation also assumes that the Lurgi and Fischer-Tropsch processes (i.e. existing proved technology) will be used for coal liquefaction and gasification, and that historical schedules will apply for design and construction of facilities. The third "unrestricted" scenario assumes that research and development are placed on a crash basis and all national resources are expanded as quickly as possible and fully devoted to the needs of a synthetic liquid fuel plant construction program. Based on the three assumptions the long term supply curves for synthetic high-BTU pipeline gas and synthetic fuel gas (low BTU), and synthetic liquid fuel are presented in graphs 2a, 2b, and 2c.

Incentives for commercial development of production facilities are important considerations related to these assumptions. Analyses were made for the various regions comparing costs of imported crude oil of \$4, \$7, and \$11 per barrel, plus a transportation cost. It was assumed that the heating value of the imported crude oil would average 5 million BTU/barrel. Based on these considerations, as can be seen from graphs 2d and 2e, from the viewpoint of utilities, fuel gas is attractive at most competing oil costs, while liquid fuel is attractive at prices of \$7 or the greater per barrel, and pipeline gas is competitive only at the higher crude prices. From the perspective of an investor (at 15 percent Discounted Cash Flow), fuel gas is competitive at the higher price levels, and liquid fuels are attractive only to \$11 per barrel crude oil. It should also be noted that commercially funded Lurgi processes are unattractive to both groups at \$4 and \$7 per barrel but become competitive for utilities in the west at \$11 per barrel. Although, under current Department of Interior research and development plans the first coal liquefaction demonstration plant will only be on-stream by late 1979, and the first coal gasification plant by 1981, this information is valid regardless of the year under consideration.

The largest and best known tar sand deposits in the United States are in Utah although other tar sands exist in New Mexico, Wyoming, Colorado, and Alaska. The largest deposits, all in Utah, contain between 22 and 27 billion barrels of oil in place with the single largest accounting for 12.5-16.0 billion barrels. The recovery of heavy oil and tar sands hinges on lowering the viscosity of oil either by solvents or the application of heat. Two methods using solvents, one which was developed by the Bureau of Mines, are being tested along with several thermal methods. Under the 5 year R&D program, at least three pilot tests in various areas of Utah tar sands, will be conducted concurrently during each of the first two years. Between one and two demonstrations will be conducted in subsequent years. With the sharp increases in the price of conventional oil, it is expected that greater interest will be vested in developing the tar sands. Based on these interests and expected developments, the following projections are made in Table 2a for the expected daily production of oil from tar sands.

The Oil Shale Task Force for the Project Independence Report indicates that there are resources of at least 1,800 billion barrels of oil, contained in an area of approximately 25,000 square miles. About 84 percent of the known higher grade reserves are in Colorado with 10 percent in Utah and six percent in Wyoming. Oil shale yields about 10-40 gallons of syncrude per ton of processed shale. Commercially viable shale requires a yield of at least 25-30 gallons per ton, which represents about 33 percent of known reserves. (According to the National Petroleum Council, the "Oil shale reserves, equivalent to 54 billion barrels of syncrude, in the Piceance Basin of Colorado and Uinta Basin of Utah are considered to be the most economically recoverable portion of the Green River Formation oil shale resources.")

Oil shale development depends upon a number of factors. These include the availability of capital at acceptable rates of return, environmental impacts including emissions from shale production facilities and water restrictions, the price of crude oil, and land availability. The Federal Government can significantly affect the level of shale oil production in the 1980's with a coordinated program involving leasing, water availability, financial incentives, R & D, and environmental approvals. Shale oil production potentials, based on appropriate incentives, are presented in Table 2b.

TABLE 2a.—U.S. UNCONSTRAINED REGIONAL PROJECTIONS FOR TAR SANDS

[Thousands of barrels per day]

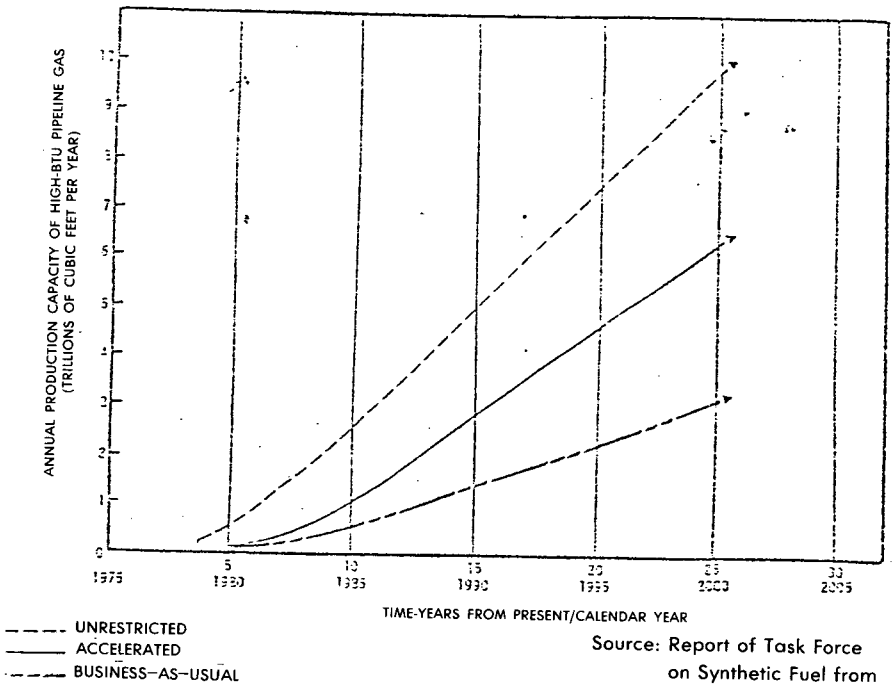
Conventional cost per barrel	1974	1977	1980	1985
Business-as-usual:				
\$4	0	0	0	0
7	0	5	25	100
11	0	5	25	100
Accelerated development:				
\$4	0	0	0	0
7	0	5	50	300
11	0	5	50	300

Source: Oil task force report.

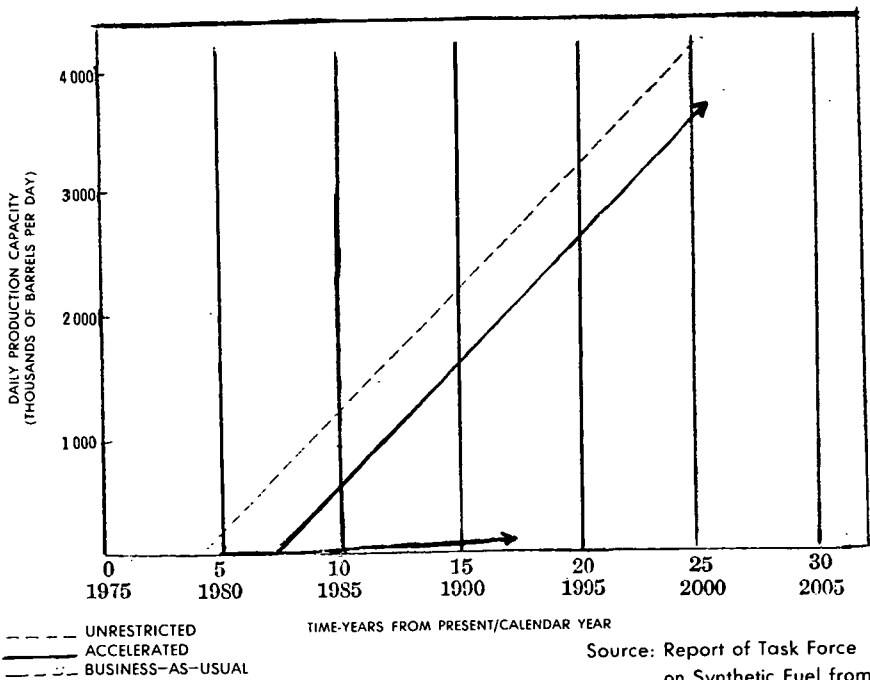
TABLE 2b.—SHALE OIL PRODUCTION POTENTIAL

	World oil price, dollars/ barrels	Shale oil production (thousand barrels per day)			
		1977	1980	1985	1990
Business as usual .....	\$7	0	50	250	450
Accelerated development .....	11	0	100	1,000	1,600
Expansion over business as usual .....		0	+50	+750	+1,250

GRAPH 2a.—Growth of Synthetic High-Btu Pipeline Gas Annual Production Capacity

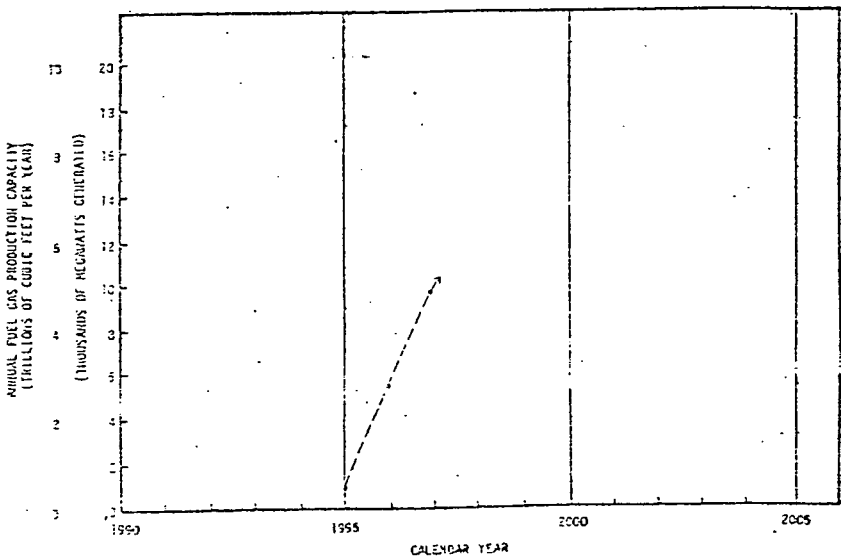


GRAPH 2b.—Growth of Synthetic Liquid Fuel Production Capacity



Source: Report of Task Force  
on Synthetic Fuel from  
Coal (p. 112).

GRAPH 2c.—Projected Growth of Synthetic Fuel Gas Annual Production Capacity and Power Generation Capacity



Source: Report of Task Force on Synthetic Fuel from Coal (p. 112).



GRAPH 2d.—Competitive Position of Synthetic Fuel Plants Under Utility Financing

		WESTERN COAL						EASTERN COAL								
SYNTHETIC FUEL PRODUCT	REGION	SOUTHERN PACIFIC COAST			NORTHERN PACIFIC COAST			NORTH CENTRAL			SOUTHERN ATLANTIC COAST			MIDDLE ATLANTIC COAST		
	IMPORT	4.05	7.05	11.05	4.10	7.10	11.10	4.50	7.50	11.50	4.05	7.05	11.05	4.00	7.00	11.00
	PROCESS															
LOW-BTU FUEL GAS	TYPICAL PROCESS	X	X	X	X	X	X		X	X		X	X		X	X
	LURGI															
HIGH-BTU PIPELINE GAS	TYPICAL PROCESS		P	X		P	X			X			X			X
	LURGI			X			X	NOT CONSIDERED								
LIQUID FUEL	FISCHER-TROPSCHE			X			X	NOT CONSIDERED								
	TYPICAL PROCESS		X	X		X	X		P	X			X			X

X—DEFINITE COMPETITIVE POSITION; P—POSSIBLE COMPETITIVE POSITION

Source: Same as Graph 2a, (p. 114).

GRAPH 2e.—Competitive Position of Synthetic Fuel Plants Under Investor Financing

		WESTERN COAL						EASTERN COAL								
SYNTHETIC FUEL PRODUCT	REGION	SOUTHERN PACIFIC COAST			NORTHERN PACIFIC COAST			NORTH CENTRAL			SOUTHERN ATLANTIC COAST			MIDDLE ATLANTIC COAST		
	IMPORT	4.05	7.05	11.05	4.10	7.10	11.10	4.50	7.50	11.50	4.05	7.05	11.05	4.00	7.00	11.00
	PROCESS															
LOW-BTU FUEL GAS	TYPICAL PROCESS		X	X		X	X		X	X		X	X		X	X
	LURGI							NOT CONSIDERED								
HIGH-BTU PIPELINE GAS	TYPICAL PROCESS							NOT CONSIDERED								
	LURGI							NOT CONSIDERED								
LIQUID FUEL	FISCHER-TROPSCHE							NOT CONSIDERED								
	TYPICAL PROCESS											X				P

X—DEFINITE COMPETITIVE POSITION; P—POSSIBLE COMPETITIVE POSITION

Source: Same as Graph 2a, (p. 114).

**Question 3.** What is the size of our recoverable domestic crude oil reserves at various prices between \$4/bbl and \$12/bbl?

**Answer.** The attached table shows the additional domestic oil reserves over and above current proved reserves which potentially could be brought into the proved category over the next fifteen years. They are shown by various petroleum producing areas and by various categories of recovery methodology. This categorization is made to indicate that not all of these reserves are freely available for development (e.g., offshore areas and Naval Petroleum Reserves) and that many of these are the potentially lowest cost domestic reserves.

Also, the price associated with these reserves are minimum acceptable prices; as is explained below, a high market price for domestic oil *does not* mean that the difference between the prevailing price and the minimum acceptable prices shown will accrue as economic rents to oil producers or owners of mineral rights (including the Federal Government). Instead, the oil available at the apparently lower price will be developed more intensively (e.g., by drilling more wells per barrel of reserves proved than was assumed in computing these minimum acceptable prices). This more intense development will tend to be carried out to the point where the minimum acceptable prices equal the prevailing or expected market price. In addition, reserves proved in offshore areas will be subject to a lease bonus; to the extent the bidding procedure is competitive, these bonuses will be of a magnitude which makes the minimum acceptable price—including recovery of lease bonuses—equal the prevailing or expected market price.

The minimum acceptable prices and reserve quantities shown in the table must be interpreted carefully in view of the assumptions under which they were made. The key assumptions are:

1. The level or intensity of development, (e.g., the number of wells drilled per barrel of reserves proved, the rate at which associated gas is withdrawn rather than reinjected, etc.) continues at historical levels despite higher market prices.
2. Two key economic rents extracted from producers—lease bonuses and rentals—are excluded.
3. Only the portion of the yet unexploited domestic resource base which might be developed over the next fifteen years—under an accelerated development program—is included. No economic information is available on reserves potentially available beyond the point.
4. The ordering of reserves by price sheds no light on the actual order in which they will be developed, primarily because a large portion of these are owned by governments. Consequently, the timing of development will be controlled by leasing decisions. Similarly, certain engineering lags prevent developing all of the lowest cost reserves before turning to higher cost ones unless domestic oil demand were low. For example, reserves available from secondary recovery projects on known fields cannot all be developed simultaneously because of age-differences among fields and the normal practice of allowing fields to produce on a free-flowing basis for a period of time prior to instituting any form of enhanced recovery.
5. The minimum acceptable prices are calculated at the wellhead. Transportation costs—for example from the Alaskan North Slope to lower 48 refining centers—can narrow the economic differences at the refinery gate of reserves which appear to be of widely varying economic attractiveness at the wellhead.
6. The minimum acceptable prices assume that oil co-products—NGL's and associated-dissolved gas—have no value. Of course, these joint products of crude will be sold and the revenues gained will make the minimum acceptable prices shown lower. They are excluded here because these revenues can only be calculated after an assumption—or a demand model which is linked to an oil and non-associated gas supply model—about gas price and liquids price is made. Moreover, the gas and liquids market prices, if known, would reduce the minimum acceptable crude prices in various regions differently due to varying gas-oil ratios and different liquid-gas ratios as well as transportation differences among regions. In a gas-rich, liquids-rich area, for example, the Gulf of Mexico, these co-product revenues could reduce minimum acceptable prices by up to \$1.00 at \$1.00 per mcf gas prices.
7. The estimates assume a 10 percent cost of capital, after tax; drilling and other costs held constant at 1973 levels; and a generally static technology except for advances in coping with deeper water depths offshore and a successful tertiary recovery technology.

8. The estimates include various costs which are not related directly to real resource costs but which are imposed by governments (royalties, state ad valorem and severance taxes, and Federal and State income taxes) as well as private landowners (royalties). As noted above, two other major categories of non-resource costs—lease bonuses and rentals—are excluded, primarily because they overwhelm resource costs offshore and cannot be calculated without an assumption about market prices.

## PROVED RESERVE ADDITIONS

[Billion barrels]

		Minimum wellhead price, dollar range per barrel									
		2	3	4	5	6	7	8	9	10	11
I. Lower 48 onshore:											
A. New fields:											
Primary and secondary					0.1	0.1	1.4	3.5	3.5	10.9	
Tertiary									.1	.5	
Subtotal						.1	.1	1.4	3.6	3.6	11.4
B. Old fields—new projects:											
Secondary			14.9	10.5	na	na	na	na	na	na	na
Tertiary						.1	.3	.8	3.4	7.0	
Subtotal			14.9	10.5		.1	.3	.8	3.4	7.0	
C. Subtotal—onshore			14.9	10.5	.1	.1	1.7	4.4	7.0	8.4	
II. Lower 48 offshore:											
A. Atlantic			.1	1.6	1.5	na	na	na	na	na	na
B. Gulf of Mexico			5.2	4.3	3.0	na	na	na	na	na	na
C. Pacific			.9	3.8	3.1	1.8	na	na	na	na	na
D. Subtotal—offshore			6.2	9.7	7.6	1.8	na	na	na	na	na
III. Alaska (Ex NPR):											
A. North Slope		9.6			6.0	na	na	na	na	na	na
B. Southern OCS			.6		.8	3.1	1.6	na	na	na	na
C. Subtotal—Alaska (Ex NPR)		9.6	.6	6.8	3.1	1.6	na	na	na	na	na
IV. Naval petroleum reserves:											
A. NPR-1		1.0									
B. NPR-4											
C. Subtotal—NPR's		1.0				10.0					

† Incomplete.

Na indicates no information available.

**Question 4.** What regulatory and distributional problems exist if the price of all domestic crude oil and refined products is exceeded by the prices of imported crude oil and refined products from foreign nations?

**Answer.** The situation outlined in the question is, by and large, the current situation. The weighted average cost of imported crude oil exceeds the weighted average cost of domestic crude oil by more than \$4/bbl, and prices of foreign LPG, distillate and residual fuels are generally higher than the prices of domestic products.

This does not create any particular distributional problems. The regulatory problem has two major aspects:

1. Major oil companies control most of the domestic crude oil production. This is a special problem in domestic "old" oil which is price-controlled at an average of \$5.25/bbl. Small and independent refiners do not have equal access to this cheap source of crude oil and, therefore, find that their crude oil costs are much higher than those of some major companies. The result is that the small refiner must price his products higher than those of companies with cheaper feedstocks, and has difficulty competing. The problem is especially severe for the "northern tier" refiners who developed an historic reliance on Canadian crude oil and have no other source of crude.

2. The eastern seaboard developed a historic reliance on imported distillate and residual fuel oil when it was cheaper than alternate fuels used in other

regions and now finds that their products costs considerably exceed the national average. This is true not only for resellers but for large consumers, such as electric utilities, especially in the northeast and in Florida, which import directly.

To some extent, the regulatory feature of "freezing" supplier-purchaser relationships as of the base period, which was essential to the equitable distribution of short supplies and to the protection of market shares and classes of trade, constrains the customer's search for cheaper sources. Since we are import-reliant, eliminating this "freeze" would not solve the problem.

We are, therefore, proposing a new regulatory device to smooth refiners' costs of crude oil and to provide relief to product importers. Alternatives were published on August 30. After a period of comments and hearings, a proposed version was published on November 11 for final comment. Implementation is expected in November.

*Question 5.* What portion of so-called "new" crude oil now being marketed was discovered, and development wells drilled, prior to December, 1973?

*Answer.* FEA estimates that all "new" oil marketed comprised only about 15 percent of total domestic crude for the first half of 1974. FEA reporting procedures up to now would require a search of state records of well drilling permits to discover how much of the "new" oil is coming from fields discovered and wells drilled after December 1973.

Given the long term cycle of seismic exploration, wildcat exploratory drilling and eventually production drilling, it can be assumed that most of the "new" oil produced in the past year has come from increased production from existing fields and wells rather than from entirely new fields discovered and developed in the past year. In any case it is estimated that not more than 1/3 of the "new" oil and probably much less is produced from new fields and pools opened in 1974.

FEA is in the process of securing approval for a new Form FEA-90 which should markedly improve the quality of crude oil production information available to us. We are revising our reporting procedures so that in the future more estimates of the kind you requested can be made from our data sources.

*Question 6a.* What portion of Alaskan North Slope crude oil would be developed at \$3.40 and \$5.25/bbl?

*Answer.* There are no present figures for examining the productive capacity of the North Slope region at rates of \$3.40 and \$5.25 per barrel since all previous Oil Task Force data were based on \$4.00, \$7.00, and \$11.00 per barrel. However, production figures associated with these prices may be representative of trends which could be extrapolated from these data. In order to assist in making extrapolations, data are presented for the price levels already analyzed. It has been assumed by the Oil Task Force that production in the Prudhoe Bay region of Alaska would begin in late 1977 under the BAU alternative with a wellhead price of \$4.00 per barrel. Production at this point would be approximately 1.6 million barrels per day and remain at that level for about 10 years.

At a wellhead price of \$7.00 per barrel, it is considered likely that further discoveries would be made on other private lands on Alaska's North Slope to sufficiently utilize the entire two million barrels per day of Trans-Alaskan Pipeline capacity. This would amount to 434,000 barrels per day of additional production by 1980. If looping is assumed in the Pipeline, its capacity could be increased to 2.5 million barrels per day and production from other private lands could double by 1985. Production from Naval Petroleum Reserve No. 4 is assumed to begin in 1985 at \$7.00 per barrel but another pipeline would be required whose capacity would be supported by producible discoveries and also control maximum production. Under both the BAU and AD assumptions the North Slope would play a significant role in United States petroleum production accelerated development—contributing about 17 percent of the total 1985 supply at \$7.00 per barrel and 15 percent of the total at accelerated development—\$11.00 per barrel. The percentages are higher for 1988 expectations, 25 and 20 percent respectively). However, it should be noted that there is uncertainty as to whether oil is present in the required amounts or whether there will be sufficiently large accumulated reserves for economic production given the exigencies of the remote and hostile Alaskan environment. These data are presented in Table 6a.

TABLE 6a.—ALASKAN UNCONSTRAINED PRODUCTION POSSIBILITIES FOR CRUDE OIL AND NATURAL GAS LIQUIDS<sup>1</sup>[Thousands of barrels per day]<sup>2</sup>

		1974	1977	1980	1985
Prudhoe Bay.....	\$4	0	158	1,600	1,600
Do.....	7	0	158	1,600	1,600
Do.....	11	0	158	1,600	1,600
Other North Slope.....	4	0	0	0	0
Do.....	7	0	0	0	0
Do.....	11	0	0	434	900

<sup>1</sup> Same for business-as-usual and accelerated development, except AD-1985, other North Slope is 2,000 rather than 900.<sup>2</sup> Includes exploration and production costs at region wellheads plus royalty and 10 percent DCF on investment but excludes lease acquisition costs and rentals.

**Question 6b.** What other domestic crude oil sources would be developed at \$3.40 and \$5.25/bbl?

**Answer.** Using our assumed oil prices at \$4 and \$7 a barrel, oil production would take place by 1977 off the Outer Continental Shelf on the West Coast, and the Atlantic Coast; although at \$4 a barrel, production would fall off in the later years projected under the business-as-usual assumption. Given accelerated development, the coast drilling would still be developed as in the case of BAU and, even at the \$4 price, development would increase through 1988. In addition, under accelerated development the Naval Petroleum Reserve No. 1 would be developed by 1977 at \$4 a barrel, but shows decreasing production after 1980 at that price and at all three prices, \$4, \$7, and \$11. Production will also be expected at \$4 and at \$7 a barrel for Prudhoe Bay by 1977 to continue throughout the period projected. (PIB Oil Task Force Report, Page I-3-4.) Other North Slope oil not including Prudhoe Bay, will increase under both alternatives by 1980 at \$7 and \$11 per barrel and will decrease after 1985.

The development of oil which would be secondary or tertiary production would be from the two-thirds of oil reserves which have remained in the ground after normal oil development. However, due to increasing costs, it appears very likely that this more costly-than-normal attempt to recover crude would not be made at the low end of the price spectrum. Under accelerated development conditions, it was estimated that about one third more tertiary recovery of oil could be made in 1985 at \$11 per barrel than for the BAU scenario. This amounts to an additional 800,000 barrels per day.

**Question 7.** What is the size of the gap between domestic demand and domestic production of crude and refined oil products (a gap which must be closed with imports and through energy conservation efforts) at domestic prices for "old" crude of \$5.25/bbl, and

- "new" crude priced at \$11/bbl.,
- "new" crude priced at \$7/bbl.,
- "new" crude priced at \$5.25/bbl.,
- "new" crude priced at \$11/bbl., with all crude on which development wells were drilled before December 1973, priced at 5.25/bbl.,
- "new" crude priced at \$7/bbl., but with all crude on which development wells were drilled before December 1973, priced at 5.25/bbl.,
- "new" crude priced at \$5.25/bbl., but with all crude on which development wells were drilled before December 1973, priced at \$5.25/bbl.

**Answer.** To obtain an adequate projection of the long run supply/demand balance for crude petroleum, the influences of other energy sources were held constant for supply and only slightly considered for demand analysis due to the complexities that such a dynamic model would entail. The basic sources for this study were Project Independence and U.S. Energy Outlook, both of which utilized a similar model for obtaining future supply/demand projections. These projections were modified in regard to the FEA regulatory definitions of domestic crude types and then used to show what long run influence various price mixes would have upon the supply/demand balance.

The effects of redefining the base date for oil oil from May 15, 1973, to December 31, 1973, was not addressed for it was determined that this would have a minimal effect upon the price structure. More specifically, it was determined that such a change would effect the relative weight of old in the later years of the projection.

## DEMAND

Based upon the following long-range determinants of energy demand: (a) economic activity (G.N.P.), (b) cost of energy, (c) population, and (d) environmental controls, the National Petroleum Council in U.S. Energy Outlook, adopted a 4.2 percent growth rate as a base, as indicated in the following table:

PROJECTIONS OF U.S. TOTAL ENERGY DEMAND UNDER THREE DIFFERENT SETS OF ASSUMPTIONS

	Growth rate (average annual percent gain)			(Quadrillion Btu's)	
	1970-80	1981-85	1971-85	1980	1985
High.....	4.5	4.3	4.3	105.3	103.0
Intermediate (initial appraisal).....	4.2	4.0	4.2	102.6	124.9
Low.....	3.5	3.3	3.4	95.7	112.5

Source: National Petroleum Council.

Applying these growth rates to the average rate of monthly crude runs to stills for the year of 1973 and the first six months of 1974 one can obtain a projection of total demand for crude oil (See Table 7a).

Using 12,275 bbls/day as the base total demand for crude oil in 1975, the National Petroleum Council's expected high growth rate of 4.4 percent per annum was added to yield the following projections of demand:

*Total crude oil demand (In 1,000 barrels per day)*

1974 .....	12, 275
1975 .....	12, 815
1977 .....	13, 895
1980 .....	15, 515
1985 .....	18, 215
1988 .....	19, 835

## SUPPLY

Based upon the various requests made, supply projections were adopted from the supply projections of Project Independence as made in the Task Force Report on Oil: Possible Levels of Future Production in order to yield supply projections at the prices of \$5.25/bbl, \$7.00/bbl and \$11.00/bbl. With this in mind, the following supply projections were derived:

SUMMATION OF UNCONSTRAINED DOMESTIC PRODUCTION POSSIBILITIES FOR OIL, NATURAL GAS, LIQUIDS HEAVY CRUDE AND TAR SANDS

Price per barrel	1974	1975	1977	1980	1985	1988
\$5.25	9.5	9.0	9.2	9.9	10.1	10.3
7.00	9.5	9.1	9.5	11.1	11.9	12.1
11.00	9.5	9.2	9.9	12.2	15.1	16.4

Source: Project independence oil task force report, possible levels of future production.

These findings are well founded and explicitly justified in the Task Force Report: Sustained growth in those projections at the \$11.00 level differ from earlier studies with lower estimates by relying upon new major sources of crude oil. Such new sources include:

## NEW SOURCES OF CRUDE OIL

Source:

Secondary production on shore.....	2, 800, 000
Tertiary production on shore.....	2, 650, 000
Alaskan North Slope.....	2, 329, 000
Gulf of Mexico OCS.....	981, 000
California OCS.....	668, 000
South Alaska OCS.....	518, 000
Heavy crude oil and tar sands.....	440, 000
Atlantic OCS.....	110, 000

## DOMESTIC SUPPLY AND DEMAND BALANCES

Continual development of new sources, as well as the depletion of older fields will vary the relative amounts of "new" and "released" and "old" domestic crude over the long run. After viewing the depletion rate of a sample of 25 unrelated fields, the following projections of category mix were made (given the relative category mix for 1974).

## RELATIVE PERCENTAGES OF CRUDE OIL BY TYPE

Type	1974	1975	1977	1980	1985	1988
New.....	37.70	40.35	45.65	52.60	66.85	75.80
Old.....	62.40	59.65	54.35	47.40	33.15	24.20

Utilizing these changing mix projections, the "gap" between domestic supply and total demand for crude oil at various price combinations may be estimated by weighting total volume by the amounts available under each price category.

## CRUDE GAP AT \$5.25 PER BARREL FOR OLD OIL AND \$11 PER BARREL FOR NEW

	1974	1975	1977	1980	1985	1988
Supply.....	9,500	9,080	9,510	11,132	13,429	14,923
Demand.....	12,275	12,815	13,895	15,515	18,215	19,835
Gap.....	2,775	3,735	4,385	4,383	4,786	4,912

## CRUDE GAP AT \$5.25 PER BARREL FOR OLD OIL AND \$7 PER BARREL FOR NEW

	1974	1975	1977	1980	1985	1988
Supply.....	9,500	9,031	9,327	10,543	11,292	11,664
Demand.....	12,275	12,815	13,895	15,515	18,215	19,835
Gap.....	2,775	3,784	4,568	4,972	6,923	8,171

## CRUDE GAP AT \$5.25 PER BARREL FOR ALL OIL

	1974	1975	1977	1980	1985	1988
Supply.....	9,500	9,000	9,200	9,900	10,100	10,300
Demand.....	12,275	12,815	13,895	15,515	18,215	19,835
Gap.....	2,775	3,815	4,695	5,615	8,115	9,535

TABLE 7a.—CRUDE OIL, PRODUCTION, IMPORTS, AND STOCKS, 1973, 1974

	Crude runs to stills (1,000 barrels per day)	Domestic production (1,000 barrels per day)	Imports (1,000 barrels per day)	Stocks (1,000 of barrels)
1973:				
January.....	12,190	9,179	2,732	237,469
February.....	12,187	9,373	2,873	235,362
March.....	12,201	9,175	3,162	244,131
April.....	12,208	9,233	3,049	248,783
May.....	12,281	9,303	3,215	257,867
June.....	12,862	9,209	3,220	248,857
July.....	12,750	9,195	3,501	243,673
August.....	12,636	9,161	3,593	248,314
September.....	12,560	9,077	3,471	241,276
October.....	12,758	9,172	3,740	246,297
November.....	12,374	9,144	3,452	249,998
December.....	12,150	9,041	2,981	242,478
1974:				
January.....	12,039	8,907	2,382	233,035
February.....	11,661	9,156	2,248	240,723
March.....	11,895	8,950	2,462	244,665
April.....	11,725	9,038	3,235	258,574
May.....	12,128	8,980	3,649	270,300
June.....	12,351	8,982	3,551	272,627
Average.....	12,275	9,117	3,140	

Chairman HUMPHREY. Now, Congressman, do you want to open up with the questions on this since you listened to the testimony here

Representative BROWN of Ohio. Mr. Chairman, I would appreciate that, since the House goes in at noon, and we may have a quorum call right away. And I can dispatch my questions I think very quickly.

I would like to ask my questions of all of you generally if I might. First, what about the progress that has been made in secondary and tertiary recovery in recent years? I understand that the average recovery from oil wells in the United State at present is about 32 percent, and that there are methods by which that recovery can be increased to 48 percent in some wells, or that that would be the average percentage of recovery that you could get from U.S. wells, given certain economic circumstances and, of course, certain geological circumstances in the wells. This is the question: To what extent does secondary and tertiary recovery at the present world price of oil indicate a vast tappable supply of oil from present U.S. wells that seem to have run their course? Can I get a comment from each of you?

Chairman HUMPHREY. Go right down the line.

Mr. MOODY. Well, I will attempt to answer that. In the National Research Council estimates we contemplated an overall average recovery of about 40 percent, which is somewhat in excess of the number of 32 percent that you mentioned. And this was because we are anticipating additional quantities of oil to be recovered with improved technology and improved prices. But, as far as we could see, we would be lucky to get as much as 40 percent on the average.

Now, we do know of oil fields where we can get 90 percent recovery, commercially right now. But these are unusual.

Representative BROWN of Ohio. Unusable? For what reasons?

Mr. MOODY. They are unusual.

Representative BROWN of Ohio. Unusual. I beg your pardon.

Mr. MOODY. Unusual geological configurations. On the other hand, from a lot of oil fields, for example, from a lot of the heavy oil fields in California, we will be lucky if we get 15 or 20 percent, even with all of the improved recovery mechanisms that we can devise like steam flooding, fire flooding, and all kinds of exotic things.

Representative BROWN of Ohio. At the high price?

Mr. MOODY. At the high price, that is right.

Representative BROWN of Ohio. Could you estimate, or could anybody quantify the number of barrels of oil that might be brought out of U.S. wells at various price levels, say \$11 price? What are we likely to be able to get out of existing wells that could not be brought out of those wells a year ago, because of secondary and tertiary recovery?

Mr. MOODY. I could not guess in terms of barrels, Congressman. I could say that of the unrecoverable oil as we presently see it in the United States—some 200 billion barrels—we might hope to get half of that with increased R. & D. efforts.

Representative BROWN of Ohio. You are talking about a state of the art beyond that which we now have I am speaking really about the state of the art which we already have and about the impact of the economics on the utilization of that technology. Do you follow what I



am saying? In other words, my suggestion is that we have technological abilities which are not practical except at certain prices per barrel of oil. Now my question is: At the \$11-a-barrel price, and with the technology we now have, how much additional oil are we likely to be able to bring out of existing wells?

Mr. MOODY. I could not guess in terms of barrels, but it would be an appreciable increment, if the old oil were reclassified and obtained the new price. I could not guess at the number.

Representative BROWN of Ohio. So what you are giving me is a guess of what is geologically feasible to recover if technology were advanced beyond the point to which it has advanced now?

Mr. MOODY. That is right.

Representative BROWN of Ohio. Does anybody else have a comment? Mr. McKelvey.

Mr. McKELVEY. I am not saying, Congressman, that I have a way of knowing. It has been a puzzling and a very interesting problem to all of us. I have no way of knowing how much additional oil could come at present prices or is, in fact, coming as a result of increased incentives by way of secondary recovery. But the trade journals frequently are carrying reports of new secondary and tertiary projects that have been installed, and there seems certainly to be substantial new activity in that area. But quantitatively, what it would be I have no estimate.

Representative BROWN of Ohio. Anybody else? Mr. Emery.

Mr. EMERY. Maybe the problem is a bit more complicated than just the \$11 a barrel, because if the price were made \$11 a barrel, and if it proved economical to extract the oil from oil shale at that price, there would have to be some assurance that the price would not drop, say, to \$7 as soon as the plant was built.

Representative BROWN of Ohio. Well, let me just say that the estimate of Project Independence for secondary and tertiary recovery, new projects in old fields, was at 3.4 billion barrels at a \$10 price and 7 billion barrels at a \$11 price. Now, does anybody feel that that is an unreasonable estimate, or do you have any comment to make on that estimate?

Mr. EMERY. I would just make one comment. At the present rate of use, that is about a year's supply.

Mr. McKELVEY. Congressman, I do not recall that figure precisely, but we estimated that, under the business-as-usual assumptions with a price of \$11 a barrel, that is 1985, out of a total I believe of about 16 million barrels a day, about 5 million could be coming from secondary and tertiary recovery projects, and nearly another half million barrels a day might be coming from heavy crude oil and tar sands which might be using a similar technology. And for the accelerated development case, we estimated that an additional 800,000 barrels a day might be added from tertiary recovery onshore, and that about 300,000 additional could come from heavy crude oil and tar sands.

Representative BROWN of Ohio. I have very little time left. I want to ask one other question and that is about the effort to make a geological determination before you drill the hole. Mr. Moody, I am very much concerned, quite frankly, as someone who believes that this is a risk or a venture effort that ought to be undertaken by individual citi-

zens; I recognize there are tax breaks they get to do this, but I want to try to keep the Government out of the business of drilling dry holes. I know that given the tendency of the Federal Government to want to do things of that nature, that the prospect of being able to drill dry holes for half a million dollars or \$2.5 million or something like that is going to be very difficult for the Government to resist. But my question is about the prospect of being able to know what you are going to find when you drill, has that improved substantially with seismic undertakings? I have been shown some of these reading maps that have a squiggly line on them, and the shadows that are created by the squiggly lines bouncing back and forth after a seismic explosion. That is a fairly new process; I mean I have been told that that is a fairly new process. Is that really going to give us a better chance to know what we are going to find under the ground, and has that improved in recent years?

Mr. MOODY. In the last few years there has been a significant development in exploration techniques that are variously called bright spots, bright-spot technology and other similar names. It is possible, under favorable geological conditions and with adequate technology, adequate data gathering, data interpretation, data processing, to predict with some accuracy whether or not there are hydrocarbons in that particular tract. This obviously will increase our success ratio. It will increase our ability to determine whether or not there is oil there or not, but it will not increase the amount of oil that is actually in the ground.

Representative BROWN of Ohio. Now, you can give me some idea of what the cost of that present drilling effort might be? I am advised that it can cost up to half million dollars before you ever drill the first hole in order to determine as much as you can about what is down there, and that this is one reason that a lot of oil companies do not want to be forced to yield up to everybody else the data that they have gathered prior to the drilling of the hole. Can you give me some advice on what those costs are, anybody?

Mr. MOODY. Well, on a single project basis it is sort of hard because you have to take into account a lot of additional shooting. I can say that on the average a major company probably spends \$8 million to \$10 million in seismic and subsurface geologic work in preparation for an offshore sale. That is sort of out of the air, off the top of my head as a number.

Representative BROWN of Ohio. Okay. Now I just want to understand, again I want to get your terms right. When the Federal Government sells or leases offshore lands, you are telling me that, before a company goes in and makes the investment in that lease, they have spent, in order to determine which leases they want to bid on, as much as \$8 million?

Mr. MOODY. On the average, per sale, yes.

Representative BROWN of Ohio. And this is the seismic effort, and I suppose other things that they might do?

Mr. MOODY. Yes. Largely seismic. Largely seismic.

Representative BROWN of Ohio. And so that is the reason, I guess, that they do not want to give up that \$8 million worth of technical information that they have paid for?

Mr. MOODY. And additionally the proprietary position in a competitive bidding situation.

Representative BROWN of Ohio. OK. Thank you. My time is well past.

Chairman HUMPHREY. Thank you very much.

I want to come very directly to Mr. Carlson's statement. In your testimony you outline some steps that you think are appropriate to take, Mr. Carlson. You say a paper should be prepared describing the techniques used for estimating reserves, and then you call for a meeting of experts and a process of revising the estimates. Who do you think should call that meeting of experts that you feel is necessary to give us more accurate information?

Mr. CARLSON. At this point I think that a number of different channels can be used. Obviously this is not an expensive procedure. We can do it in the Government, or Resources for the Future and other nonprofit organizations are in a good position to call such a meeting, or any other instrumentality that seems to make sense.

Chairman HUMPHREY. Mr. Perry mentioned that the Resources for the Future would call such a meeting. Do you think that would be adequate?

Mr. CARLSON. Sure. In fact, it may turn out that more than one meeting makes sense to explore different aspects of this.

Senator, I might point out that the world has been shocked by a change of economic environment since October of 1973, inasmuch as the price boosts have occurred on the cost side and the product side. I think that has a great influence on the estimates of reserves and it is appropriate for us to go back through our techniques, as was noted by the experts here, because the current estimates are based on 1973 data. We know the world is quite different now from 1973, so I think this is an appropriate time to go back over the variables, as well as the methodology being used, to see where we come out in our estimates. I frankly believe that, if these prices do stay up at high levels, then we are going to see our estimates of reserves at a much higher level than we have in the past.

Representative BROWN of Ohio. Mr. Chairman, could I interrupt? I am going to be obliged to leave.

Chairman HUMPHREY. Indeed. We appreciate your cooperation.

Representative BROWN of Ohio. Thank you, and now if you will excuse me. Gentlemen, thank you, and I apologize also.

Mr. CARLSON. Before Congressman Brown leaves, just commenting on the matter of public exploration, we had a lease sale off of Mississippi. We sold that lease of 5,700 acres for \$210 million, and the company that purchased it has drilled four holes, all dry, at around \$10 million. If I were coming up to testify before this committee to justify our program, and if we were doing this in a public exploration program, I would be hardpressed to explain the expenditures, given the political environment that people in the public sector have to work in. Risk taking is best handled in the private sector and not in the public sector.

Representative BROWN of Ohio. That is my feeling, but I am just scared to death that the Federal Government is going to find it very difficult to resist that opportunity.

MR. CARLSON. Inasmuch as bureaucrats have a tendency to play it safe, you will find the cost per barrel discovered will go up considerably in the future.

Representative BROWN of Ohio. And also it's what the Federal Government tends to do with its money, you know, it seems to come from nowhere, and the urge to bestow it on somebody is almost irresistible.

Chairman HUMPHREY. Mr. Carlson, you mentioned the present price levels.

MR. CARLSON. Yes, sir.

Chairman HUMPHREY. Is there any indication that these price levels might break and come down?

MR. CARLSON. Well, that is a matter of considerable conjecture. When we had our experience with the OPEC countries, some of us went back in history to see what other cartels we had experienced, and if you look at the other major cartels we have had, but nothing nearly as large as OPEC, you will find out that cartels, in terms of maintaining a fixed price, do not last long—2 to 3 years—and when production and capacity exceed consumption, they tend to fall apart. You find that alternative sources of supply, either of substitutes or of the cartelized commodity, play a very major role in undermining the cartels. If the consumer, in fact, treats each cartel member separately and encourages him to go back to market and thereby to capture most of the market, the cartel breaks sooner.

So, based on history, you will have to say that this cartel will not have a long life, maybe less than 3 years. But this is a unique cartel, and its damage to this country is so great that you would want to hedge, even if you thought there was a high probability of its falling apart in 3 years. Consequently, I think what the Congress and the administration are considering as an energy program is very important and appropriate.

Chairman HUMPHREY. I do not think there is any doubt that we all believe that there has to be an extensive conservation program. I believe that all of the witnesses here today have indicated that, regardless of the size of the resource estimates, the low or the high, that it is only a matter of timing as to what kind of a policy you pursue; that ultimately you have to have conservation and also alternative sources of fuel.

If your higher resource estimates are right, you have got more time to work out your program of research, development and exploration and pricing. If the lower estimates turn out to be correct, you simply have to proceed a little more rapidly, and possibly at greater cost because of the hurry-up. The rush program is more costly than the more sustained, leisurly path that might be appropriate under the higher estimates.

I notice that in Kuwait recently they were selling some oil at \$8.50 a barrel. Kuwait is one of the large producers, is it not?

MR. CARLSON. Yes, Senator, there have been indications in the press that several of the producing countries are concerned about their foreign exchange earnings and want to increase them. They made commitments on gifts, as well as commitments to spend money in other ways, so it may be very difficult to continue to cut back production as the world's total consumption goes down, and inventories are signs in

terms of changes, of returning to the market and somewhat lower prices.

Chairman HUMPHREY. Yet the administration has made a proposal of a floor price to the OPEC countries.

Mr. CARLSON. But that floor price is lower than the price that the OPEC countries have set.

Chairman HUMPHREY. What is it, \$7?

Mr. CARLSON. Well, there have been proposals ranging up to \$7.70, and others have been around \$5, and so there has been a range of alternative lower prices. No specific price has been stated by the administration, however.

Chairman HUMPHREY. Mr. Kissinger stated one.

Mr. CARLSON. Yes, Mr. Kissinger said \$7.70. Of course, then you get to the question of whether you index that price, whether that is the real relative price over time. Then you get into the same range of those that start with \$5, where they may index that over time, and it may be a comparable figure.

But right now, the administration is not proposing a particular figure. And, as you know from the news conferences that have come out of the International Energy Agency, there is considerable discussion among other consuming countries as to the appropriate floor price.

And the chairman of that organization is talking about a price somewhat below \$5. So there is a considerable range here.

In contrast, however, the administration has talked about guaranteeing price for a particular new industry, like an oil shale industry, or a coal gasification industry, or coal liquefaction, to bring those infant industries into being. Then, given time, they will become competitive, we hope, and so we will have this other source of energy coming along on a timely basis. But that means selective price control, or guaranteed price, or some other mechanism. That is a proposal.

Chairman HUMPHREY. Your recitation of the history of cartels being unable to maintain a rigid price structure I think is most informative and helpful. But I sense that we have not pursued as aggressively as we should the development of alternative fuel sources.

In other words, if you are going to break the power of a cartel, you have to have market mechanisms and other sources of supply that threaten this cartel's control over price and production. And, therefore, I would imagine that this cartel is not really being tested, as others have been.

For example, we have a steel industry. I do not say it is a cartel, but in the steel industry we have alternative metals. The aluminum industry competes with it. Steel can put its price up, but if the aluminum industry decides to be competitive, it can at least in certain types of steel products be competitive as an alternative, a substitute metal. I do not see that happening in any degree in the oil cartel situation.

Mr. CARLSON. Now, the leadtimes are fairly long in terms of going out and finding a new and promising area, exploring it, finding out that there is oil there and bringing forth that oil. However, I am encouraged by the last 18 months. Outside of the OPEC countries new discoveries of reserves have gone up to around 15 billion barrels

and that could mean 2 million to 5 million barrels of production daily within the next 5 years. So prices have a tremendous incentive effect.

Now in our own country we have not allowed the incentive effect of price in these older fields.

Chairman HUMPHREY. But we have in the newer areas, and they have not been doing very well.

Mr. CARLSON. Oh, on the contrary. I think the incentive structure is such that people are pulling out their rigs and investment in old wells and going for the new oil, because the new price is there.

Chairman HUMPHREY. Yes, but how much have they discovered?

Mr. CARLSON. Well, we have the leadtime problem when we go into an area, and this takes a few years. It does not happen overnight or in 1 year. But I am convinced that if we find some way to take care of the loss of the consumer buying power, which is a real problem in a time of recession, and allow the old crude oil price to go up and have the market incentive, then we are going to bring forth considerable additional oil from the fields discussed here.

Chairman HUMPHREY. What is the price of crude now?

Mr. CARLSON. \$5.25.

Chairman HUMPHREY. But what was it before that?

Mr. CARLSON. It was less than that.

Chairman HUMPHREY. About \$2, was it not?

Mr. CARLSON. You would have to go back some time.

Chairman HUMPHREY. Or \$3 in 1971 or 1972.

Mr. CARLSON. About \$3.50, I think in early 1973, but you also have had considerable inflation, and it is much higher than the CPI inflation. You ought to see what inflation is doing out in the oil field.

Chairman HUMPHREY. Yes, I understand.

Mr. CARLSON. What has happened is the price was set at \$5.25 in December of 1973, and because of inflation, and because that became a more binding price, we have created a disincentive for people even to search for more oil in these fields, particularly to undertake the higher cost secondary recovery methods.

Chairman HUMPHREY. Is there not a surplus of oil right now?

Mr. CARLSON. Yes, worldwide.

Chairman HUMPHREY. Yes. So, why do we not buy up some, then, for the reserves that we are talking about? I have heard every Government witness that we have had here, or at any other committee, say that we have got to have a reserve. What are we doing about it? Why don't we buy some?

Mr. CARLSON. In fact, you will find that private stocks throughout the world are the highest they have ever been in history.

Chairman HUMPHREY. I am talking about not private stocks, they are not adequate reserves. We do not rely on Winchester and Remington to keep the reserves of ammunition. We buy them through the Pentagon and they are stuck away in holes in the ground all over the world. We do not rely upon Union Carbide to keep reserves of atomic materials, or something. We have Government facilities. I am not necessarily happy about that, but that is the situation.

What is the Government's program on reserves besides talk?

Mr. CARLSON. The Government programs and the bills presented to the Congress—title II of the President's energy bill—was to provide a reserve of 1 billion barrels, and to fill that reserve perhaps from our

petroleum reserve No. 1 in Elk Hills or other sources; to fill that up on a timely basis. It is now before the Congress.

Chairman HUMPHREY. And you feel that there is no existing authority under the strategic stockpile legislation to build these reserves?

Mr. CARLSON. No, sir. Not to build a billion barrel reserve.

Chairman HUMPHREY. I did not say a billion.

Mr. CARLSON. A billion barrel reserve, excuse me.

Chairman HUMPHREY. Billion barrels.

Mr. CARLSON. No, we do not have the authority to do that. Now, obviously the Defense Department is helping a little bit more these days, and obviously the private sector is helping more, so we have higher inventories, but for the kind of an inventory that you are talking about, we need legislative authority.

Chairman HUMPHREY. You need legislative action in the Congress?

Mr. CARLSON. Yes, sir.

Chairman HUMPHREY. Do you believe we ought to buy those reserves on the international market, or are you saying that they ought to come out of our own domestic supplies?

Mr. CARLSON. I think the marginal barrel, wherever it is taken, will have the same impact on the market unless in fact we take barrels out of petroleum reserves that we might not otherwise have taken out. Then that is on additional supply source.

But, in any case, on some timely basis. In fact, we have had the responsibility of doing the analysis on whether it is wise to have strategic reserves and how you go about getting them. We have an advisory committee that is looking into that and we will be glad to share their results in April and May.

Chairman HUMPHREY. This meeting, Mr. Perry, that you talk about, when do you think you will organize that?

Mr. PERRY. Well, we have already done some of the planning and we are hoping to get the people together in the next 2 or 3 months.

Chairman HUMPHREY. Will you have the cooperation of the Federal Government agencies?

Mr. PERRY. We fully expect to have.

Chairman HUMPHREY. I think it is very important that that be done.

Mr. CARLSON. Senator, I might point out that the National Academy Committee report that is the subject of your inquiry was primarily financed by the Federal Government, the Geological Survey and the Bureau of Mines, and we are very pleased that it was done. As you can understand, there are different points of view, some of which differ with the Government viewpoint, but we want to make sure that the information is out in front of the public.

Chairman HUMPHREY. Very good.

I will run through a few questions here. Again, Mr. Perry, I wish you would keep us informed as to the date of that conference.

Mr. PERRY. We certainly will do that.

Chairman HUMPHREY. And we want to have some of our staff people to attend, and hopefully some of the committee members.

Mr. McKelvey, most of the disparity between your estimates of oil and gas resources and those of other experts result from the dis-

parities for the contiguous 48 States. In gaging the amount of undiscovered oil remaining in the known oil producing basins in the States—that is exclusive of Alaska and Hawaii—the Geological Survey had a discovery rate of 0.5 to 1.0 times the historical discovery rate for the basins.

Yet the National Academy panel concludes that a rate of 0.1 would be more appropriate, based on what it terms the rigorous statistical work of Mr. W. King Hubbart. Is the range of uncertainty really this great in setting the proper level of this parameter? Cannot this disparity reasonably be narrowed?

Mr. McKELVEY. Well, Mr. Chairman, this is a matter of great interest to us and, indeed, as a result of the discussion that has taken place in the last year or so on this problem, this question is under review by our resource analysis group. And it is certainly being reconsidered.

But, it is very difficult to establish what is a reasonable figure, and as I think I indicated in my testimony, very likely it ought to vary from one area to another. First of all, there are geological differences, and some areas have been more fully explored than others, and it is quite possible in one given province that entirely different factors ought to be used than in another one.

But, I think as all of the witnesses here this morning have mentioned and agreed, the uncertainty is always going to be there, and probably the estimates ought to be expressed as a range in nearly all cases. And I do not think that any of us know good ways at present to reduce that uncertainty very much. We may make judgments as to different values that ought to be used in a given area, but still, until the drill gets there, there is no way of telling whether a given area has oil or gas.

Chairman HUMPHREY. Might I ask both you and Mr. Perry and the other witnesses, can you give us your personal opinion about which end of the spectrum of the so-called estimates is more plausible?

Now, we have had all kinds of estimates made. They always make the headlines, and immediately people are writing letters that flood the mail. The mail is incredible. You cannot imagine, gentlemen, what hits us when these stories come out.

First of all they want to know, what are you doing about it, like somehow or another a Member of Congress can immediately go out and drill 10 oil wells and assure us of an extra million barrels a day. Incredible.

I was on a radio show yesterday up in Philadelphia. I took some questions, and when I got through I asked myself whether this was really necessary, because the questions were not the kind of questions that sought thoughtful analysis. It was—why aren't you doing this; why aren't you getting us some more oil, Senator; why haven't you started the coal gasification; why haven't you done this; and, didn't you read that report.

One said to me, didn't you read that report that came out from that group of scientists; aren't you frightened; what are you going to do about it.

Now, help me. Where do you come down in this wide range of estimates? Do you feel it is the upper or the lower end or where is it?



Mr. McKELVEY. Mr. Chairman, I indicated earlier that we have to recognize this very wide range as probably being a valid one in the present circumstances. Maybe the wonder of it is, as I think Mr. Emery indicated, that it is as small as it is.

Personally, while I have not participated in the preparation of any of these estimates, although my name has been associated with some of them over the years in which I have coauthored papers and reports with others who have been involved in making the estimates, I have to say that I have been, and I think still am inclined towards the higher range, in my own thinking, about what our potential is. I always try to make the distinction, however, that this by no means is a forecast of what is going to be found much less what is going to be produced.

It is an indication of the size of the target that might be there for exploration. What I think is really important, however, and this is particularly true at this stage in history, is to recognize that in all of these estimates, even the lowest, they are saying that a very large amount of oil remains to be discovered, 70 billion barrels, or 72 billion.

Chairman HUMPHREY. Discovered and recovered?

Mr. McKELVEY. And recoverable at present prices and with present technology, 72 billion barrels, which is the lowest of the estimates of the undiscovered, recoverable, and producible petroleum. That is a lot of oil.

Chairman HUMPHREY. You are speaking now of U.S. supplies?

Mr. McKELVEY. United States alone. You cannot be sure.

As Mr. Moody mentioned, the lowest estimate could be too high, and the highest estimate could be too low. But we hope that we will be able to narrow that range with intensive work in the next few years.

But it is important to be doing the right thing, and I think the right thing in this case is to be encouraging exploration, looking for other oil and trying to develop other alternative sources, and practicing energy conservation more widely.

Chairman HUMPHREY. Mr. Perry, do you have any comment on that?

Mr. PERRY. Well, I do not want to anticipate the results of our forthcoming conference, so I would like to reserve, if I could.

On the other hand, it seems to me that there are a number of things you would do in any case, and that it would probably be prudent to do at least the initial planning around the lower number. I guess Mr. McKelvey and I look at the same half glass of water in different ways.

Seventy-two billion barrels does not seem like an enormous amount to me when we are using something around 6 billion barrels a year now. And if we do not do something more to control the growth rate of demand in the future.

Mr. CARLSON. Excuse me Mr. Chairman?

Chairman HUMPHREY. Yes, Mr. Carlson. And may I say to the others, if you all want to pitch in here, that's fine.

Mr. CARLSON. Mr. Chairman, because the present estimates of recoverable resources were made during a time period when the price

was considerably lower, I would have to say that a reconsideration of those estimates should tend to raise them because of the impact of price. The price elasticity has an impact on reserves just like it does on supply, and I have to believe that reserves must be much higher than the old 1973 estimates, when the price was down, as you say, at \$3 and \$4 a barrel, instead of \$11 a barrel.

Chairman HUMPHREY. I never could understand what price had to do with what was under the ground.

Mr. CARLSON. You talked about *recoverable* resources, and we talked about the 395 billion barrels estimated to be there, but we are only recovering a small fraction of that. Your colleague mentioned 32 percent recovery. That may go up, as he said, to 48 percent because of higher price, and that is where you get the higher estimates of resources that are recoverable.

Chairman HUMPHREY. I just wanted to clarify it. In other words, you are talking about recoverable resources not total resources.

Mr. CARLSON. No.

Chairman HUMPHREY. And there is a difference between resources and reserves. Reserves are a more practical economic figure, is that the way you would put it?

Mr. CARLSON. Recoverable resources is the only meaningful figure to me. But I think that, when you start having incentives to go out and explore for recoverable resources, you are going to find some more that are recoverable, so your total universe may well increase in time, because you have an incentive to be out there more. So I think the figure has to be up near the higher end of the range at the current prices, in real terms.

Chairman HUMPHREY. Mr. Emery.

Mr. EMERY. I would like to address a little different aspect of this. Seven years ago Chairman Humphrey spent a couple of days with us on the ship *Atlantis II*.

Chairman HUMPHREY. Yes, indeed.

Mr. EMERY. And we had discussions aboard this ship as to the geology of George's Bank as we were passing over it, and part of the discussion was on the need for putting down some test holes on George's Bank to find out what the oil potential really was. We had information from seismic sources and other sources, geophysical sources, but no holes. Today, 7 years later, we still have no holes.

The point is that regardless of how well we make the estimates of undiscovered resources, these estimates are based on indirect data, and we really do not know that the oil and gas are there until the holes have been put down. This means that for the Atlantic coast we have to say that the reserves are somewhere between zero and a large amount. We have got to do better than that.

Chairman HUMPHREY. Why did we not put down the holes? I think I know why, but I would like to have this stated.

Mr. EMERY. Santa Barbara came along a couple of years later.

Chairman HUMPHREY. Yes, and worries about oil slicks and environmental problems.

Mr. Emery, another question: Your estimates were published in 1975. Do these estimates take account of the price factor, the price increases? In other words, did you relate price to your evaluation of the estimates?

Mr. EMERY. No, we had to base it on the data for 1973, because the data for 1974 were not out yet. In fact, they are still not out.

Chairman HUMPHREY. The price figures, of course, were available and I think the question that I am asking is whether or not the increase in price gave you any feeling that the amount of recoverable resources was larger because of the price increase?

Mr. EMERY. We know it has to be higher, but we cannot know how much.

Chairman HUMPHREY. Mr. Moody?

Mr. MOODY. We tried to strike some kind of a mean between oil that is recoverable under the existing price structure and the projected price structure, and oil that is conceivably recoverable, because that would be 100 percent of it.

We could, if the price were right, go in and mine every bit of oil out and get it out, but that is obviously an unreasonable thing to contemplate.

Chairman HUMPHREY. That is just sheer theory?

Mr. MOODY. That is right. So, we took what we thought was a reasonable approach, considering economics, price, and what was technologically feasible to extract, and that is where we came up with our 40 percent.

Chairman HUMPHREY. Now, this question to Mr. McKelvey again. You indicated in your testimony that the Geological Survey is now reappraising U.S. resource potential based on large bodies of new data. Do you expect that the revised estimates of oil and gas resources will be lower than your past estimates, and if so, significantly lower?

Mr. MCKELVEY. Mr. Chairman, I have not been in close contact with that group, but I understand that their preliminary thinking is that they probably will be using a somewhat lower factor than the 0.5 to 1.0 for relating to past discovery rate, and that very likely may 40 percent under a program of phased price decontrol.

Mr. EMERY. Well, I would feel that it will not rise under the present price regulation, but I think John Moody has some additional information.

Chairman HUMPHREY. Mr. Moody.

Mr. MOODY. I would doubt if the output of natural gas would rise much, whether it was decontrolled or not. The only really great amount of gas that we can see, that conceivably could come on, is the gas that is tied up in tight formations in Colorado, New Mexico, and a few other places, and what is needed there is research, is injection of capital to make the tests and see if that gas can be gotten out. We could double the U.S. gas potential if we were successful in getting the gas out of these tight formations.

But, if you go and talk to some of the gas transmission lines, they cannot find the gas. The gas is in tight supply.

Mr. CARLSON. Mr. Chairman, I think that the market incentive is not here in this area either, because on the average, natural gas is being priced at about \$1.75 a barrel, and if you had a higher price you would have a higher incentive for people to look for that natural gas. I really think you cut down your curtailments 3 to 5 years out and have considerably more natural gas than you would have otherwise if you could decontrol just new natural gas—I'm not talking

about the old gas under the old 20-year contracts—but the new natural result in some decrease in their estimates.<sup>1</sup>

Chairman HUMPHREY. Well, is that not rather paradoxical, in view of the big increases in crude oil prices in the past 18 months?

Mr. McKELVEY. Well, Secretary Carlson indicated that this is a matter that is to be looked at, but what I was referring to has to do with undiscovered resources, and it is closer to the amount that is in the ground rather than how much will actually be produced. It is quite possible that, looking at from the standpoint of the prospects of production, there should be some increase in what would be expected and in what, let's say, the proved reserves would actually be.

Chairman HUMPHREY. Mr. Emery, estimates by the MIT energy laboratory indicate that natural gas output would rise about 20 percent from 1975 to 1980, even with continued price regulation, and that it would rise about 40 percent under a program of phased price decontrol.

Do your findings conflict with this judgment?

Mr. EMERY. I do not think so. Maybe I did not understand you.

Chairman HUMPHREY. Well, the question was that MIT says that natural gas output would rise about 20 percent under existing prices is from 1975 to 1980, that is with continued price regulation, and it could rise by some gas. That happens to be a proposal that is before the Congress.

The thing that bothers me—and I see I have to charge off for a vote—is that the natural gas is owned by the oil companies. There is no real competition. If they do not own it all, then most of it. Now, if the steel companies owned the aluminum companies and every other competitive metal, what would be the incentive for competition from a substitute metal?

The oil companies own the crude, they own the tankers, and own the pipelines, they own the refineries, they own a good deal of the coal, and they own most of the natural gas, that is the proven reserves of natural gas. They control the middleman, they own him, and now they own most of the filling stations. It is an unbelievable setup. I mean, what makes anybody think that market forces really work in this kind of a situation?

If I owned, if I was the farmer out there that owns the farm, and also owned the grain reserves, the storage, owned the railroad, owned the processing and owned the wholesalers and the supermarket, why you would pay and pay and pay. There would not be any competition.

Mr. CARLSON. Mr. Chairman, I think most of the scholars on the subject feel that there is workable competition at the wellhead for natural gas, and so they argue that Federal regulation is harmful. And I think we have enough evidence of curtailments to show that

<sup>1</sup> In June, 1975, the United States Geological Survey released Geological Survey Circular 725 entitled "Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States." This publication sharply reduced the U.S.G.S. estimates of these resources. It stated, "Within the probability levels of 95 percent and 5 percent, the range of total undiscovered recoverable oil resources is 50 to 127 billion barrels. The range of undiscovered recoverable gas is 322 to 655 trillion cubic feet, and the range of undiscovered recoverable natural gas liquids is 11 to 22 billion barrels." A covering letter from Mr. McKelvey to Chairman Humphrey stated, "The report deals with crude oil, natural gas, and natural gas liquids onshore and offshore to a water depth of 200 metres recoverable at pre-1974 price/cost ratios . . . next year we plan to broaden the scope of our appraisal to include economic analysis, nonconventional sources, and the continental margin beyond 200 metres water depth."

Federal regulations are harmful, and a deregulation—going back to that workable competition—is worthwhile to pursue.

Chairman HUMPHREY. Well, I think we have to do something about it.

Gentlemen, you have been here a very long time. I have a number of questions.

Let me ask you this. We are just starting this series of hearings. You have been most patient, and I have subjected you to considerable delay because, without prior notice, my testimony before the Banking Committee took longer than expected. We do not have a way to computerize our committee meetings.

Would you let me ask you, would you be willing, at least some of you to return at the request of the committee as we pursue this? We are trying to get a basis of information to start out with. There are matters that we want to talk about on the pricing and the relationship to production. We need to know a good deal more about estimates of recoverable reserves or resources. We need to pursue this.

Gentlemen, I have a number of questions that I would like to put to you. I realize, however, that your time is limited, and we will ask for some written answers to some questions.

[The following questions and answers were subsequently supplied for the record:]

RESPONSE OF VINCENT E. MCKELVEY TO WRITTEN QUESTIONS POSED BY  
CHAIRMAN HUMPHREY

*Question 1.* You indicated in your testimony that the Project Independence Oil Task Force, which you chaired, based its estimates of future oil output rates on estimated, unknown but recoverable oil resources in the United States of 127 billion barrels. The task force found that output rates could be substantially increased under so-called accelerated development policies. Yet this estimated resource base is only slightly larger than the estimates by the National Academy panel (113 billion barrels), which led the panel to conclude that a large increase in U.S. production is very unlikely. Can you indicate how the Project Independence Oil Task Force derived its oil output projections? Can you clarify how much strikingly different conclusions on future production possibilities could be based on such similar assumptions about the resource base?

*Answer.* The Oil Task Force derived its estimates of production under explicit assumptions as to the effect of finding rates, costs, prices and other factors for exploration and development, and for secondary and tertiary production development (See pages III-1 to III-35 of the Task Force Report for the details of the methodology and general assumptions).

In brief, the procedure consisted of projecting the oil output as the result of an imposed exploratory drilling schedule, but conditioned to economic viability as a function of the expected price per barrel of oil.

Consideration of the magnitude of the potential reserves required a verification that "the sum of the potential reserves plus reserves as of end 1973" would not be exceeded by "the sum of cumulative production over the projection period and of a working reserve allowance equal to 10-years of the production rate at the end of the period." Under the assumptions of accelerated development and \$11 per barrel—the maximum production case—the cumulative production between 1974 and 1988 would be 73.2 billion barrels, and the 1988 reserve would be 80.7 billion barrels. Their sum is equal to 153.9 billion barrels, which is somewhat smaller than the sum of the 1973 reserves of 46.9 billion barrels and of the NPC estimate of undiscovered recoverable reserves of 127 billion barrels.

Moreover, the Oil Task Force also assumed that 16 billion barrels of the cumulative production would come from the recovery of the oil remaining in place (nearly 300 billion barrels) in already discovered fields and that 2 billion

barrels would come from heavy crudes and tar sands (against resources estimated by the Bureau of Mines to be 107 billion barrels and 22-27 billion barrels respectively).

Therefore, under the assumed maximum effort condition the resources assumed to be available would not be exceeded. These resources assumed to be available are essentially of the same magnitude as those estimated by the National Academy Committee.

From the statements of the Academy Committee members at the hearing, it seems that the committee made none of these calculations, but merely judged that production could not be increased much as the result of changes in economics or policies.

*Question 2.* The Geological Survey's current estimates of undiscovered recoverable oil resources are higher than those used by the Project Independence Oil Task Force. If the Survey's estimates are accurate, would they not imply that future output rates still higher than those projected by the Project Independence Blueprint are attainable or, alternatively, that lower domestic oil prices might be adequate?

*Answer.* Cumulative production over a given period of time, cannot, of course, exceed the amount that is discoverable and recoverable but within that constraint production is limited by other factors. Some are incentives for exploration, finding rates, and extraction capability.

The PIB analysis showed that production would be responsive to both prices and policies, and this conclusion was reached also by most reviewers as well as by a number of investigators (See II-15-18 of the PIB Oil Task Force report).

*Question 3.* The oil output projections of the Project Independence Blueprint are higher than those of the National Academy of Sciences, but the Blueprint's projections for natural gas are quite conservative. The latter foresee a sharp decline in gas production under continued price regulation and a very small increase with deregulation and accelerated development policies. Is there a discrepancy between the Blueprint's projections for oil versus gas? Can you clarify this apparent contrast?

*Answer.* While the PIB Oil and Gas Task Forces met together during the early phases of the study, they made their estimates and wrote their reports independently. I have not had an opportunity to check apparent discrepancies or the reasons for them. But, as mentioned before, the methodology and assumptions made for the oil projections are explicitly stated in the Oil Task Force Report.

*Question 4.* You stated in your testimony that projections of undiscovered recoverable oil resources such as those by Mr. Hubbert "assume that the course of future petroleum exploration and production is an inexorable one, regardless of major modifications in economic conditions, technological advances, or public policies." Are you saying that such estimates, for instances, take no account of large recent price increases for crude oil? Do prices, policies and technology play a role in your estimates?

*Answer.* I believe Mr. Hubbert has indicated that he sees no way in which price increases can effect production except through increased recovery of oil in place—which he doubts would be substantial.

The estimates of the Survey's resource appraisal group are not predictions of ultimate production but represent targets for exploration and increased recovery technology. Prices, policies, and technology play an explicit role in the PIB oil estimates—in fact an important role in how much will actually be produced.

*Question 5.* You stated in your testimony that the approach used by Mobil Oil Company "focuses on areas believed to be prospective," and you indicated your belief that "a pool of industry appraisal would lead to a somewhat higher estimate than that of a single company. . . ." Do you feel that the individual company estimates on which the National Academy panel relied to a considerable degree were based on inadequate data?

*Answer.* Each company making such estimates can be presumed to have available all public information (which is essentially what the Geological Survey possesses) plus private information that it has acquired on its own or by "trading" with other companies. Its data base can be extensive, but its appraisal of what may be found in individual "plays" is its own and may not be the same or as good as another company's based on the same data plus its own

proprietary data. The sum of the industry's ideas, if that were available, can be safely assumed to be better than any of its parts.

Also, in comparing estimates of something so elusive as undiscovered petroleum deposits, one must consider the specific needs of the entities making the estimates. An oil company will tend to estimate the amount of oil which it knows how to find, and if the estimates are to be made public it would further consider whether all the extent of its knowledge should be revealed. This is a legitimate bias in a competitive business, such as oil exploration, but it should be kept in mind. On the other hand, a public agency such as the Geological Survey tends to estimate what could be found, given that the proper policies and steps be adopted by government; such estimates are targets for exploration and technologic advance rather than predictions of what will be found and produced.

*Question 6.* The experts seem to agree on the considerable oil potential of Alaska, the outer continental shelf, and of secondary and tertiary recovery from already depleted oil fields. Most of your disagreement with the National Academy panel's resource estimates concerns estimates of oil to be extracted conventionally from the continuous 48 States. Why is there less agreement about the potential of a relatively accessible well-charted area than about that of inaccessible and uncharted territories and the potential of little used extraction methods?

*Answer.* The disagreement is not with the National Academy Committee, which made no calculations of its own but only selected an intermediate value for the total U.S. undiscovered resources from the various estimates is considered. The disagreement is with those of the Mobil and Sun Oil Companies.

The difference between the Survey's resource appraisal group estimates and those of the companies probably arise from the different methodologies—the play versus the volume approach. The explorationist (Mobil and Sun), trying to appraise how much he can find in a fairly well known area based on the information available to him is likely to arrive at a lower estimate than one that uses volume of unexplored sediments, without a special constraint of identifiable plays. In totally unexplored areas, knowledge of specific prospects necessarily plays a less important role in judging the potential. The agreement of experts on the oil potential of undrilled areas is more apparent than real—it denotes a common level of ignorance of what geologic conditions are rather than a high degree of accuracy on what they are.

---

RESPONSE OF KENNETH EMERY TO WRITTEN QUESTIONS POSED BY  
CHAIRMAN HUMPHREY

*Question 1.* The National Academy panel did not adopt the data or estimates of any of the previous estimators of unknown but recoverable oil and gas resources. Rather it formulated its own estimate, which lies above most of the company estimates and below most of those put out by the U.S. Geological Survey.

Please explain in more detail just how the panel reached its estimates of 113 billion barrels of undiscovered, recoverable oil resources and 530 trillion cubic feet of undiscovered, recoverable natural gas. Why do you feel that your methods and results are superior to the others?

*Answer.* The National Academy panel did not formulate an independent estimate of undiscovered oil and gas resources. At least 1,000 man years have been spent upon making such estimates by oil companies and perhaps 50 man years by government agencies, so the panel with its limited time and budget could only investigate the methods used in making the previous estimates. These methods are five in number, some more complex and subtle than others, and they are briefly outlined on pages 87-91 of the panel's report. As also discussed briefly in the text the panel made a judgmental estimate based upon the previous estimates and their probable strengths and weaknesses. This judgmental estimate was 15 billion tons purposely left in round numbers to indicate its uncertainty. Eventually, this number was editorially translated into 113 billion barrels—a three-digit number that implies more precision than exists.

*Question 2.* The experts seem to agree on the considerable oil potential of Alaska, the outer continental shelf, and of secondary and tertiary recovery

from already depleted oil fields. Most of your disagreement with the Geological Survey's resource estimates concerns estimates of oil to be extracted conventionally from the contiguous 48 States. Why is there less agreement about the potential of a relatively accessible, well-chartered areas than about that of inaccessible and uncharted areas and the potential of little used extraction methods?

*Answer.* In 1972 the U.S. Geological Survey estimated 230 billion barrels of recoverable undiscovered oil in the contiguous 48 States. By 1974 the U.S.G.S. reduced its estimate to 110 to 220 billion barrels (220 was based upon a recovery factor of 1.0; 110 upon a factor of 0.5). A factor of 1.0 would imply that the undrilled strata are just as oil rich as those that have been drilled; 0.5 means that they are only half as rich on the average. The panel considers that both factors are too high and agrees with Hubbert's findings that a more reasonable factor is 0.1; this would yield a total undiscovered resource of oil amounting to only 22 billion barrels—which accords well with estimates based upon other methods.

*Question 3.* The largest differences in recoverable resource estimates concern the contiguous 48 States. Yet even the Project Independence Blueprint concedes that conventional oil production in the lower 48 States is likely to decline substantially except at high prices. Moreover, the Project Independence Oil Task Force, which made the oil output projections for the Blueprint, based its work on an estimate of undiscovered recoverable oil resources only marginally higher than that of the National Academy panel. With such basic elements of similarity and agreement, how can the two sets of experts come to such diverse conclusions about potential oil output?

*Answer.* The panel did not use Project Independence estimates. Last sentence answered in (2) above.

*Question 4.* Estimates of U.S. proven reserves have not been changed in response to the huge price increase for oil. But we know that potential recovery must have increased markedly through greater potential for secondary recovery methods. Your estimate of 51 billion barrels for the U.S. proved and prospective reserves seems to be based squarely on the uncorrected API proven reserve estimate of 35 billion. Do you believe that a revision of reserve estimates on this account is necessary and would promise to yield significant increases in reserve estimates?

*Answer.* Of course more oil will be produced at higher prices than at lower ones. However, I believe that the oil companies still face very great uncertainties in the price structure that the federal and state governments will permit. Witness, for example, the existing considerable confusion about import taxes, windfall profits taxes (but not compensation for lower than normal profits), depletion allowance, price and volume control, interstate shipment of gas, widely advertised congressional discussions about replacement of oil-company exploration by government exploration, cancelling of offshore leases (Santa Barbara Basin), and withholding of important offshore areas (Destin Dome). Until these uncertainties are cleared I suspect that there is no real way to improve the estimates. In any case, the oil reserves could scarcely increase by more than a factor of two, which is pitifully small compared with the other potential sources of oil—the oil shale and coal, whose development is similarly being handicapped by similar uncertainties about government regulation and price structure. The same uncertainties, of course, have reduced investor interest in oil companies and electric utilities, and thus reduced the financial abilities of these organizations to do their jobs.

Chairman HUMPHREY. I am going to take the liberty of asking some of you gentlemen to come back again, if you don't mind, and I express my appreciation and thanks for your splendid cooperation and your very helpful testimony. I believe that we have gained some information here today that can be very helpful to us.

Thank you very much. I am going to place in the record this study of the long-run energy supplies by Professor Nelson Peach at the University of Oklahoma. It was done under contract with the Joint Economic Committee.



[The above-mentioned study follows:]

# THE LONG RUN SOLUTION TO OUR ENERGY PROBLEM

(By W. N. Peach, University of Oklahoma)

## INTRODUCTION

The world, including the United States, is generously endowed with energy resources but the American people are more confused now than they were a year ago about the "energy crisis". Frustrated motorists, waiting in long lines at filling stations, at times become violent when they learn, as they arrive at the pump, that the station has no more gas. They are upset about the fuel allocation program and about conflicting statements by public officials. They are willing to turn down their thermostats to conserve energy, but are angry at what they consider to be an unfair allocation. These and other frustrations can be expected to become more widespread as the shortages become more acute.<sup>1</sup>

Dividing up a continuously decreasing supply through some sort of rationing scheme is not a sensible solution to our present predicament. Rationing inadequate supplies may or may not result in a more equitable distribution, but few will quarrel seriously with the statement that the long run solution of the energy shortage is an increase in supply.

Potential energy supplies are available to meet our present and projected demand for the indefinite future. We should begin immediately to open our vast offshore lands for exploration and development. This should include, in addition to the Gulf Coast, the East and West Coasts of the United States. We should develop the oil and gas deposits on the North Slope of Alaska and the Cook Inlet with all possible speed. We may need additional pipelines from this area to the lower 48 states. Negotiations can be begun with Canada immediately to develop that country's vast tar sands, which are reported to be approximately the size of the proved reserves of the Middle East and North Africa.

Secondary and tertiary recovery of oil from existing wells holds the promise of a substantial increase in our oil supply. There are more than 100,000 of these wells already in existence. Generally speaking, primary recovery methods have extracted about 30 per cent of the oil in place. Secondary and tertiary recovery can add an additional 20-30 per cent to the amount recovered from existing wells, or a total of 50-60 per cent of the oil in place. Our most abundant fossil fuel is coal. Technological improvements in gasification and liquefaction of coal hold the promise of meeting our demand for energy for a thousand years.

The oil shale in Colorado, Wyoming and Utah contains upwards of 10 times as much oil as the proven reserves in the Middle East and North Africa. Occidental Petroleum Company has recently announced an *in situ* process for extracting the shale, thereby avoiding virtually all the ecological damage. We must proceed with all possible speed to begin extracting this shale oil. People have long known that geothermal energy deposits in the United States are enormous, clean, and cheap. One such plant has been operating for more than fifteen years about eighty miles north of San Francisco. Geothermal energy has been used in Italy since 1904, has been used in Iceland, France, Russia, New Zealand, Japan, and Hawaii. The technology is well known and it is relatively cheap.

Nuclear power plants can provide a third or half of our electricity requirements, if the plants can be made safe. Fusion reactor research is now going on and this produces more plutonium than it uses in the process of making electricity.

If the sources just enumerated are developed to anything like their full potential with existing price levels and existing technology, it can solve our energy problem for thousands of years. Thus, there is no shortage of energy in the United States. What is needed is a substantial development effort.

Outside the United States, the U.S.S.R. is more than sufficient in petroleum and natural gas. As a matter of fact, Russia not only meets its own needs, but meets a considerable part of the needs of her satellite countries and is in

<sup>1</sup> Written in December, 1973.

process of providing natural gas to Western Europe and supplies of petroleum and natural gas to Japan. The North Sea is rapidly becoming a major world producing area in both oil and natural gas. This should meet a considerable part of the needs of the United Kingdom and perhaps other countries in Western Europe. The potential for oil and gas in the East China Sea is enormous, and this provides another alternative to Middle East and North African oil and gas, which is precisely what the world needs at the present time.

If the known sources are developed in the United States and elsewhere, there will no longer be an energy shortage, and alternate sources can be developed. For example, solar energy for heating and cooling is available now. The speed with which alternative sources will be developed depends mainly on the change in relative prices of the different energy sources. The production of enormous amounts of electricity from solar sources is some years away. Hydrogen is another of the exotic sources, but it produces no pollution. This is a major possibility, although up to date it has been used mainly to power a few cars in the United States. Plasma, which is a few miles up in the air, offers the potential of a virtually inexhaustible source of supply if certain research problems can be solved.

The use of garbage as a source of fuel is another possibility that holds considerable potential for the United States. Although used on a widely scattered basis in the United States up to the present, it can meet a large share of our electricity needs in the future.

Although privately owned companies will provide most of our energy needs in the future, it is recommended that government owned TVA-type corporations should become involved much more so than at the present in research and development and in the actual operation of various sources of energy such as exploration, production, and distribution of energy. A tentative schedule through 1985 of the work of these government corporations is provided toward the end of this study.<sup>2</sup>

#### ENERGY SUPPLY IN THE LONG RUN

The energy goal of the United States in the long run (and the not so long run) is to provide an adequate supply of energy to meet our needs, at the most reasonable prices, from the most dependable sources, and within the most environmentally acceptable circumstances. As the events of October 1973 adequately demonstrate, the United States must find an alternative source of energy to the Middle East and North African supplies of oil and gas. During late 1973 and early 1974 there were thinly veiled threats that the United States might undertake retaliatory action against the Arab countries for their embargo on oil and gas shipments to the United States. As a result, during January 1974 two Middle East countries (Kuwait and Saudi Arabia) announced that they had wired main oil fields with explosives that can be set off at a moment's notice. The announcement further stated that the Arabs were fully prepared to blow up their oil wells if the United States used force.<sup>3</sup> Despite hundreds of millions of dollars of propaganda to the contrary, it can be stated without fear of successful contradiction that the United States now possesses the supplies, the technology (although it will doubtless be improved), to produce all the energy it needs for the next several hundred years, at currently prevailing, or somewhat higher, prices, and under environmentally acceptable circumstances. What America needs now is to ignore the flood of pessimistic, scare-type propaganda and to get on with the task of developing its known resources and those of other countries as alternative sources. At the very worst, the United States faces a period of three to five years during which the number of barrels of petroleum and their products may remain relatively constant or even decline slightly. During that period mandatory allocation to priority users (hospitals, police departments, etc.) seems inescapable. At the end of that period, the "energy crisis" as it is known can be an unpleasant past episode for the next few hundred or few thousand years.

It is simply not true, as current propaganda would have us believe, that little or nothing can be done before the year 2,000 to relieve the tight energy

<sup>2</sup>The writer wishes to thank his colleagues, Professor Benjamin J. Taylor, John A. Hodgson and Ryan Amacher for their helpful suggestions throughout this undertaking. The views and recommendations, however, are solely those of the author and do not necessarily represent those of his colleagues.

<sup>3</sup>*The Washington Post*, January 9, 1974, p. A 14.

supply situation. And repetition of this false or misleading propaganda a million times does not add anything to its credibility.

It seems that under current and prospective conditions, we can expect further increases in energy prices, but it is not necessarily true that cheap energy prices are a thing of the past. That will depend on future supply and demand situations, and new discoveries may well bring prices down.

Nor are these additional sources of energy to be considered exotic, in any meaningful sense of the term. Surely, for example, the drilling for oil and gas offshore a quarter of a century ago would have been considered exotic, although now it is one of the most widely used devices in searching for energy. Many of the additional sources of energy have been known to exist for decades, even hundreds of years. Some of them were not economically feasible a few years ago, but recent relative price increases have now made them feasible.

There is a lead time between the start of construction of facilities to produce energy and the delivery of energy in commercial quantities. Conoco, a major oil company, in a recent full page ad, gives some ideas on the lead times, after all environmental permits and plants are approved. (Table 1) There is reason to believe that, with a national commitment, these lead times can be substantially reduced.

TABLE 1.—Lead time required between the start of facilities to produce energy and commercial delivery

	Years
Nuclear electric generating plants.....	8
Fossil fuel electric generating plants.....	5
New oil/gas production.....	3-8
Shale oil mine/retort.....	4
Coal gasification.....	4
Alaskan pipeline.....	3-4
Refinery construction.....	3
Underground coal mines.....	3-4
Surface coal mines.....	2-3

Source: *The Washington Post*, Nov. 16, 1973, p. A 23.

We may list some of the more obvious additional sources of energy available in huge quantities to the United States. Others will be enumerated later. Perhaps the most obvious source of additional oil and gas is a vast expansion of offshore drilling—in the Gulf Coast area and in the Atlantic and West Coast areas, where it is estimated that less than one per cent of the area has been explored. But the area thus far explored is now providing more than 15 per cent of our domestic oil and gas.

We are only beginning to explore the vast deposits of oil and gas in the North Slope of Alaska and the Cook Inlet. The cost of bringing a barrel of North Slope oil (or 1,000 cubic feet of natural gas) to the surface is so low that, even with high transportation costs, it is now believed that this oil and gas can be delivered to the big East Coast market at approximately one third the cost of domestically produced oil and gas. The Alaskan pipeline of Zaldez, for transshipment to the West Coast, has been approved by both houses of the Congress, but three or four additional pipelines may be needed almost immediately to bring the oil and gas to the Midwest and East Coast markets. Congress might well hold hearings into the need for these additional pipelines.

In addition, new deposits of oil and gas are being discovered in the Arctic region of Canada. Canada also has immense tar sands that can be developed. For example, in January 1974 it was announced that construction had begun on the second commercial tar sand plant northwest of Edmonton, Alberta, Canada with a capacity of 125,000 barrels per day. Cost of the plant is set at \$1 billion. The first plant, completed in 1967, now produces 60,000 barrels per day. Estimates are that 20 to 25 plants will be constructed in the next 30 years. Total recoverable reserves of tar sands are estimated to be 340 billion barrels, about equal to the proven reserves of the Middle East.<sup>4</sup> Canada is interested in extending its markets beyond the United States and wants an arrangement

<sup>4</sup> See: *World Oil*, January, 1974, p. 19, and *Ibid.*, "Oil from Canada: Should the U.S. Depend on It?", pp. 47-50. See also the article entitled "At Last, Canada's Tar Sands Look Economic," *Business Week*, January 5, 1974, pp. 42 and 43; and *Ibid.*, p. 78, the editorial entitled "Developing the Tar Sands."

whereby other countries will get some of her exports. But, part of the excess over Canada's needs might logically augment U.S. supplies.<sup>5</sup>

With the higher prices now prevailing for crude oil, secondary and tertiary recovery of oil from the half a million wells already operating in the lower 48 states might add significantly to our supplies. The technology for this is already well developed. Higher existing and prospective prices make this more attractive. To date our oil wells have produced approximately 30 per cent of the oil in place. Secondary and tertiary recovery might make it possible to recover from many areas as much as 60 per cent of the oil in place.<sup>6</sup>

It is everywhere conceded that our coal reserves constitute our most abundant source of fossil fuels, enough to last for hundreds of years. Yet coal is now providing us with less than 20 per cent of our total energy used. The technology for coal gasification and liquefaction is well developed in the United States. In Russia, Western Europe and Japan it is also well developed. We can tap this great source of energy at any time and it will last indefinitely.

In a recent issue of a leading petroleum industry periodical three major oil companies announced significant developments in coal use. Gulf Oil Corporation announced a new catalytic coal liquefaction process that produces coal liquids which can compete favorably with synthetic natural gas from coal and oil from the Arctic and American offshore areas not now explored. Standard Oil of Ohio announced through a subsidiary that Old Ben Corporation plans a \$73 million multi-company project to test the commercial potential of converting coal to a low sulphur, clean burning fuel. Construction of a demonstration plant will take five years and will be located near Toledo, Ohio. Finally, Exxon announced an accelerated multi-million dollar coal use technology development program aimed at using coal as a nonpolluting fuel, including direct use of high sulphur coal. The company has converted coal into synthetic gas and synthetic oil on a pilot scale at its Baytown, Texas refinery.<sup>7</sup>

There are some 17,000 square miles of oil shale deposits in the Green River area of Colorado, Utah, and Wyoming. Both the federal government and private industry have been conducting experiments in the area for decades. The area is reputed to contain trillions of barrels of low sulphur petroleum, which can be extracted at below prevailing prices, with the technology currently available. This is by far our largest source of domestic petroleum. This source alone could solve our petroleum problem for centuries. All that is needed is to begin production immediately.

Along this line, the U. S. Department of the Interior in early January 1974 put up for bids about 5,000 acres of oil shale lands in Colorado in what the Department termed a "prototype" oil shale leasing program. This was the first offering since 1968 when the highest bid amounted to \$500,000. Successful bidders in 1974 were the Standard Oil Company of Indiana and Gulf Oil Corporation. Together, their bid was 400 times as large as was bid on the 1968 offering. These two firms bid \$210 million on about \$5,000 acres in northwest Colorado, or about \$40,000 per acre.

Industry has been aware of these resources since World War I and there has been periodic interest in oil shale since that time. But the cost of producing oil shale was much higher than the cost of producing crude from conventional methods and no commercial products have emerged for that reason. In addition to the two successful bidders in January, others were the Sun Oil Company of Delaware, a consortium made up of Marathon Oil Company, American Petrofina of Texas, and Phelps-Dodge Corporation. Among others were Atlantic Richfield Company, Ashland Oil, Inc., and Oil Shale Corporation, and Occidental Oil Shale, Inc.<sup>8</sup>

One week after the January bidding, Occidental Petroleum Company announced that one of its subsidiaries, Garrett Research and Development Company, had developed a method of getting oil from shale with an *in situ* process. Essentially the method consists of blasting a chamber inside the oil-bearing rock. Natural gas is then injected into the chamber and fired. The resulting high temperatures separate the oil from the rock. The oil seeps to the

<sup>5</sup> *Ibid.*

<sup>6</sup> See, for example, the article by Ted M. Geffen, of Amoco Production Co., "Improved Oil Recovery Could Help Ease Energy Shortage," in *World Oil*, October 1973, pp. 84-88.

<sup>7</sup> *World Oil*, January, 1974, p. 9, and *Ibid.*, 10 and 17.

<sup>8</sup> *Business Week*, January 12, 1974, p. 22; an article by Philip Fradkin, "\$210 Million is High Bid for Oil Shale," *The Washington Post*, p. A 1; and *The Wall Street Journal*, January 4, 1974, p. 1.

bottom of the formation where it is pumped away. The expanding shale gradually fills up the chamber. There are two significant advantages in the new process, compared with other methods. Heretofore, the rock was blasted, then crushed, and then to a retort where the crushed rock was heated and the oil was extracted. This presented enormous ecological problems, since, in the rich oil shale areas, only about 30 gallons of oil (called kerogen) could be extracted from a ton of shale. Under the new method developed by Occidental the ecological problem would be virtually nonexistent. The second advantage is it reduces the cost of extracting a barrel of oil shale from about \$5.00 to \$1.18. The cost estimates were made by an independent Stanford research group.

If this story is substantially correct (and there is no evidence to lead one to doubt it), the ecological nightmare feared by various environmental groups will have disappeared, and the nation can get on with the task of developing its most abundant source of petroleum, and an alternative to Middle East oil will have been found. Trading in Occidental stock is reported to have been heavy and a massive government program on the scale of the Manhattan project, was being considered to develop the oil shale lands. Occidental engineers maintain that a crash program could relieve the energy shortage within three years. Whether it requires three years or somewhat longer, the end of the fuel shortage is within sight. If it happens, it will not be the first time that big surprises in finding new sources of petroleum will have occurred.<sup>9</sup>

There are enormous deposits of geothermal energy available, mainly in the western states. Geothermal energy is cheap, involves minimal environmental problems, and is clean and plentiful. As yet there is only one plant, operating about 80 miles north of San Francisco. But interest in this new source of energy is growing rapidly. This is another type of energy that is not exotic. It is being used in Italy (since 1904), New Zealand, Russia, Iceland, Japan and other countries.

Recently, AEC scientists at Los Alamos, New Mexico have come up with a new method of using geothermal heat. They have drilled two holes in the ground about 15,000 feet deep. Cold water is pumped down one hole. This cold water is heated by the underground rock and then brought up the other hole as hot steam. The great advantage of this method is that it can be applied in a much broader area than the known locations of geothermal deposits.

Nuclear powered plants have been built or are being built rapidly in the United States. Many persons believe that these plants will provide us with a third or half of our electricity by 1985. One difficulty with nuclear plants is that many persons believe they are not safe. Fast breeder reactors are being developed and the United States government is pouring hundreds of millions of dollars into various experiments. The fast breeder reactor generates more plutonium than it uses. Although the fast breeder reactor is not expected to produce significant quantities of electricity until the end of this century, it is significant that France is about to build one. Perhaps some of the French technology could be borrowed by the United States.

From the viewpoint of the world-wide supply-demand situation, two other notable developments in recent years may be mentioned. The principal demand for petroleum and natural gas in the world is the United States, Western Europe, Japan and the U.S.S.R. The U.S.S.R. is more than self sufficient in both petroleum and natural gas. In addition to satisfying her own needs and that of her satellite countries in Eastern Europe, she is now in the process of making arrangements and installing pipelines to supply a considerable part of the demand in Western Europe. The U.S.S.R. has the largest reserves of natural gas in the world and here reserves of petroleum are reported to be enormous. The two developments to be described next are the North Sea, and the East China and Yellow Seas. The North Sea is important because of the critically short supplies of petroleum and natural gas in Western Europe. The East China and Yellow Seas are important because of their potential for making supplies available to the entire oil consuming world.

#### NORTH SEA OIL AND GAS

Western Europe, the birthplace of the industrial revolution, has long had an adequate supply of coal but has had no significant amount of petroleum or

<sup>9</sup> See: Jack Anderson, "New Shale Technology Promising," *The Washington Post*, January 15, 1974, p. B 13; *Oklahoma City Times*, January 16, 1974, and *World Oil*, November 1973, p. 13.

natural gas. With the discovery of the enormous Groningen Gas Field in the Northeastern Netherlands in 1959, it was speculated that there might be additional gas deposits in the North Sea. In the 1960s the North Sea was carved up between England, the Netherlands, West Germany, Denmark, and Norway. During the 1960s exploration and development work went on in the North Sea at an increasingly feverish pace. At present some four hundred companies have joined consortia for North Sea prospecting. The companies include, in addition to British Petroleum, such giants as Exxon, Royal Dutch Shell, Phillips Petroleum Company, Amoco, Penzoid, Conoco, Murphy, Hamilton, and Tenneco. It is expected that the first deliveries of British oil from the North Sea will come ashore a few miles north of Aberdeen by late 1974, if British Petroleum's program for tapping its Forties field 115 miles east of the Scottish coast is kept on schedule. By the end of 1975 some 250,000 barrels a day of high quality crude oil are expected from British Petroleum wells, and two or three years later 400,000 barrels per day. It is expected that about half of Britain's oil requirements will come from the North Sea by 1980.<sup>10</sup> The search for oil and gas in the North Sea has been vigorously promoted at the expense of higher royalties from the exploring companies.

Half the oil discoveries to date and two thirds of the natural gas have been in the British sector of the North Sea. There have been large discoveries of oil and gas in the Norwegian sector. Since the market in Norway is relatively small, a large proportion of the finds in the Norwegian sector will be exported. Exploration work in the German sector has to date been without commercial success.<sup>11</sup>

It seems reasonably clear that the North sea will quickly become a major world producing area for oil and natural gas. Estimates of potential production, reserves, etc are being continuously revised upward. Discovery follows discovery. The oil and gas in the North Sea will be particularly important to England, and perhaps all of Western Europe.

#### OIL POTENTIAL IN THE EAST CHINA SEA AND YELLOW SEA

In the late 1960's what has been described as potentially one of the most prolific oil reserves in the world was found in the East China and Yellow Seas near Japan, Taiwan and South Korea. The discovery was made by a United States ship under contract to the United Nations. The most promising area extends along three ridges on the continental shelf between China and the Ryuku Islands in the East China Sea. A few years later, an ECAFE sponsored geophysical survey in the East China and Yellow Seas found a series of sedimentary basins in a shelf area as large as Texas, Oklahoma, and New Mexico combined. The United Nations assisted in 31 surveying projects in the hope of finding offshore oil in an area that stretches from Thailand to Korea. Some enthusiasts say the oil in the East China Sea may be several times as large as that in the Middle East.

The Scripps Foundation, which has been part of the University of California at San Diego Branch since 1912, is conducting ocean-graphic studies in the area. The Scripps Foundation receives major funding from the Office of Naval Research and more recently from the National Science Foundation. The State of California and private donors, including now Exxon, give important financial support. In addition, Exxon has provided technical advice and trained scientists to Scripps. One of the significant things Scripps is hoping to find is oil.

A number of American, European, and Japanese companies have obtained concessions to drill for oil in the East China Sea. Among them are Pacific Gulf, a subsidiary of Gulf Oil Corporation, Clinton International, Amoco, Wendell Phillips, Royal Dutch Shell, Japan Oil Development Corporation, Imperial Oil, and Standard Oil of California. The concessions have been granted by Taiwan, Japan, and South Korea. Frequently, the leases were overlapping. In addition to the leases, there have been rumors that refineries and storage facilities were being constructed in the early 1970's on the east coast of Okinawa. Pacific Gulf

<sup>10</sup> *The British Record*, March 26, 1973, pp. 1-4; and *Ibid.*, Jan. 31, 1972, p. 4.

<sup>11</sup> See: *British Record*, December 30, 1973, pp. 1-3; Detlev Rohwedder "North Sea Finds and Power Supply," *Interconomics*, No. 12, 1972, pp. 373 and 374; Robert E. King, "Interest Focuses on North Sea, Gulf of Mexico, Far East," *World Oil*, July 1973, pp. 75-80; John Nielsen, "Power: Society's Most Consumed Product," *European Community*, April, 1973, pp. 8-11; *Business Week*, September 1972, p. 74; and Irvin L. White, Don E. Kash, Michael A. Chartock, Michael D. Devine, and R. Leon Leonard, *North Sea Oil and Gas*, Norman, University of Oklahoma Press, 1973.

was attempting to line up Japanese financing for a joint-venture refinery on Okinawa.

While these developments were taking place, the technology of offshore drilling was making great strides. Only a few years ago it was possible to drill offshore in 150 feet of water. This was extended to 300 feet and then to 640 feet. Now there seems to be no technological barrier to the water depths in which wells can be drilled. It is predicted that by 1980 man will have the capability to explore for and produce petroleum reserves in any ocean in the world. Deepwater coring, which has historically been the forerunner of full scale exploratory drilling, has already been extended to the ultra deep area. Some of the cores in the East China Sea have been drilled at a depth of three miles or more.

Recently, a dispute over ownership of the offshore resources has arisen centering around ownership of the small uninhabited islands, the Senkakus. Previously, the islands had been considered worthless or nearly so. But the prospects of oil deposits have changed all that. The first territorial dispute between Japan and Mainland China erupted in late 1970 with Peking's claim to the islands. Formosa claimed ownership. So did Japan. Peking added urgency to its efforts to stop other nations from developing underwater resources which it claimed belongs to China. In a front page article in People's Daily, the Communist Party newspaper, China attacked Tokyo and the United States for disregarding an earlier warning.

The oil potential has given rise to speculation over what may happen to international relations in that part of the world in coming decades. Mainland China has not developed the technology for offshore drilling, transporting, refining, and marketing large quantities of petroleum. For these and most of the necessary capital she must depend largely on other countries. The energy hungry Japanese economy, which is dependent mainly on Middle East oil, may be freed from rapidly rising prices in that part of the world. Japanese companies already have concessions for production in the East China Sea and may participate in storage and refining facilities. Japan may also participate in manufacturing a considerable part of the piping and other materials needed for East China Sea production. The remaining group consists of the United States and Western European companies which have developed most of the world's petroleum resources and technology. If friendlier relations evolve between the United States and Mainland China over the next few years, it appears that the United States and Western European companies will have an inside track on developing the petroleum industry in the East China Sea.<sup>12</sup>

If the speculations concerning the oil potential of the East China Sea are reasonably correct, this area could provide an alternative to the world's dependence on Middle East and North African oil. This in itself would be a major boom to the big oil consuming areas of the world, that is, Western Europe, Japan, and the United States. Although importing oil from China would involve balance of payments problems, it is highly probable that the increased competition that should result would minimize the magnitude of such payments. Furthermore, in Mainland China there are an estimated 800 to 900 million people, compared with some 50 million in the petroleum producing countries of the Middle East and North Africa. The Mainland Chinese government has a vigorous development program. Hence, the market for goods in China is much greater than the potential market in the Middle East and North Africa. Even though China would get royalties and other payments for the oil in the East China Sea, trade between the country owning the oil and the countries purchasing the oil would be increased thereby so that it would not involve any problem of Middle East sheiks piling up \$20 to \$30 billion a year in foreign oil sales to the big consuming areas. China is in great need of development products.

In early January 1974 it was reported that Japanese and American oil companies expressed an interest in helping the Chinese develop their offshore oil and natural gas resources, but so far the Chinese have refused foreign participation. The oil companies have found the Chinese interested in acquiring technology and equipment, rather than participating in joint ventures.

One source of friction between China and her neighbors may be jurisdictional

<sup>12</sup> The preceding information on the oil potential in the East China Sea is adapted, with permission, from W. N. Peach and James A. Constantin, *Zimmermann's World Resources and Industries*, Third Edition, New York, Harper and Row, Publishers, 1972, pp. 393 and 394.

squabbles over who owns what in the East and South China Seas. China has already objected to the presence of an American drilling rig off South Korea's shores and China has laid claim to territories as far away as the Spratly Archipelago, halfway between Borneo and the Coast of South Vietnam.<sup>13</sup> A few days later skirmishes were reported between China and South Vietnam over islands in the Paracel Archipelago.<sup>14</sup>

#### SOLAR ENERGY

This discussion of solar energy is divided into two parts. The first part deals with some uses where the basic technology is fairly well known. It includes such things as heating homes, apartment houses, office buildings, heating for homes, and air conditioning. Also included is a discussion of the design of buildings for energy conservation, especially the experiments of the General Services Administration. The second part of the discussion deals with long range programs for using solar energy, mainly for the production of vast amounts of electricity, where the technology is not so well known and where large sums are required for research and development.<sup>15</sup>

As the shortage of energy becomes daily more evident, a variety of alternatives is being examined. The sun is our greatest source of energy, pouring on to the earth 100,000 times as much energy as the world's present electric generating capacity. The magnitude of solar energy available for use is far in

<sup>13</sup> *The Washington Post*, January 10, 1974, p. A14.

<sup>14</sup> *Ibid.*, January 19, 1974, p. 11.

<sup>15</sup> The literature on solar energy is vast and growing rapidly. A sampling of the literature, on which some of the following comments are based, follows:

"The Energy Crisis: Reality or Myth." *The Annals of the American Academy of Political and Social Science*, November, 1973, University of California Press, Berkeley.

"Solar Energy Research." A Multidisciplinary Approach. Staff Report of the Committee on Science and Astronautics. U.S. House of Representatives, Ninety-Second Congress, Second Session, Serial Z, December, 1972, U.S. Government Printing Office, Washington, 1973.

"Non-Polluting Energy—The Energy Joyride is Over." S. David Freeman, Director, Energy Policy Project, The Ford Foundation, October 1973, *Science and Public Affairs*, p. 39-40.

"New Directions for Solar Energy." Peter Glaser and James C. Burke, Arthur D. Little, Inc. October 1973, *Science and Public Affairs*, p. 40.

"Brighter Outlook for Solar Power," Graham Chedd, *New Scientist*, April 5, 1973.

"Solar Energy Utilization in Housing." Statement of Ralph J. Johnson before the Subcommittee on Energy, Committee on Science and Astronautics, House of Representatives, June 12, 1973.

"Fauquier School Experiment to Use Solar System to Heat Classrooms, *The Washington Post*, Feb. 2, 1974, p. D5.

"The Sun Breaks Through as an Energy Source." *Business Week*, May 19, 1973, p. 68D.

"New Directions for Solar Energy." Peter E. Glaser and James C. Burke, Arthur D. Little, Inc. October 1973, *Science and Public Affairs*, pp. 40-41.

"How Shall we Use the Sunlight? Let Us Count the Ways . . ." Arthur R. Tamplin, *Environment*, Vol. 15, No. 5, pp. 16-34.

"Improving Sophisticated Energy Sources May Answer Power Problems," *Commerce Today*, pp. A-8.

"Needed for Solar Energy: Formation of a Major Industry," by Dr. James B. Comly, *Professional Engineer*, p. 32.

"Power from Sun: The Search Picks Up," *U.S. News & World Report*, April 16, 1973, p. 90.

"Harnessing Solar Energy: The Potential," William R. Cherry, *Astronautics & Aeronautics*, August, 1973, pp. 30-36.

"A Solar Energy Bibliography," Robert D. Shriner and Michael Cohen, *Professional Engineer*, October, 1973, pp. 17-18.

"Bringing the Sun Down to Earth," Oliver Bell, *The Washington Post*, Dec. 31, 1972, p. C1-C2.

"Solar Power Has Bright Future," *Industry Week*, October 29, 1973, pp. 35-37.

"GSA Confronts Energy Challenges in New Building Design," Larry F. Roush, *Professional Engineer*, V. 43, October, 1973, pp. 37-40.

"The Potential of Direct Solar Energy in Planning, Madolia Hassey Mills, Council of Planning Librarians, Monticello, Ill., 1973, 13 pp.

"Future Energy Sources . . . A Look at the Exotic," Graham W. Howe, *Rural Electrification*, October, 1973, pp. 15-18.

"Solar Energy May Achieve Wide Use by 1980's," *Chemical Engineering News*, V. 51, January 29, 1973, pp. 12-13.

"Solar Power via Satellite," Peter E. Glaser, *Astronautics & Aeronautics*, V. 11, Aug., 1973, pp. 60-68.

"Harnessing Solar Energy in France." *France*. Ambassade de France, Service de Presse et d'Information, July-August, 1973, pp. 6-8.

"This Building Saves Energy," Construction, *Business Week*, November 10, 1973, p. 205.

"Solar Energy Conversion Feasible," Dr. Van W. Bearinger, *World Oil*, August 1, 1973, "Looking Ahead," pp. 9, 10.

"Power from the Sun," Rupert Swyer, *Asia Magazine*, V. 13, Sept. 16, 1973, pp. 3-5, 7-8, 10.



excess of future needs, and the supply is inexhaustible. It is also clean and involves little or no pollution.

The basic technology for the application of solar energy for space heating, domestic water heating and air conditioning is fairly well known. Solar hot water heaters are now in use in many countries including Japan, Australia, Israel, the Soviet Union, and to some extent in the United States. Solar houses are now on the market in France.

The heating system for solar houses is simple. The walls are painted dark or black and lined inside and out with thick paneling. The heat of the sun's rays is absorbed and stored between two layers of glass, much as in a hot house. The glass surface captures the rays as the dark walls absorb the heat, raising the temperature of the trapped air. This provides the house with heated walls. This form of heat produces no pollution, no noise and no odors. The glass panels and dark colors can be arranged decoratively. There is no cost for the fuel. One need only build the house. The solar systems now being developed and used complement and do not replace conventional heating and cooling units. A back up system is needed for bad weather. In some experiments the solar system may handle as much as 75 per cent of total load.

One reason solar heating is not on the market in the United States on a large scale is that other forms of energy have been so inexpensive, but, with the rising price of natural gas and electricity, the situation has changed radically. One difficulty with solar heating systems is the high initial cost, and proponents of solar energy are talking more and more about life cycle costs, that is over a period of years. For example, it costs much more to install a solar heating system than an electric or gas system, but the solar system pays for itself in seven or eight years. That is to say, the savings in what one would pay for the gas or electricity over a period of years will more than pay for the high initial cost of the solar system.

Professor George Lof at Colorado State University has had his home equipped with solar heating for fifteen years. He installed on the roof two rows of solar panels. The panels are nothing more than shallow glass boxes with several layers of transparent glass covering a black coated one. The clear glass traps most of the sun's heat bearing waves. The black surface absorbs them, raising its own temperature to well above 200°F.

All day long air flows through the panels to pick up the heat. If the heat is needed immediately, the air travels through conventional forced air ducts and returns to the panels. Otherwise, it circulates around the base of two gravel filled cylinders that rise like silos from the basement to the roof of his two story house. The gravel stores enough heat to warm the house during the evening hours. After that he depends on his gas furnace as he must do during the extended periods of cloudiness, but Professor Lof figures that his solar furnace saves him substantial amounts on his heating bills.<sup>16</sup>

Harry Thomason has built another solar house in Prince Georges County, Maryland. Thomason, a retired patent lawyer, says his system works as follows: A solar collector on the roof and a horizontal distributor pipe sends streams of water from regularly spaced holes down the roof. The water runs down black corrugated aluminum which is protected from the air by ordinary window glass. The sun warms the aluminum, which in turn warms the water. The warm water is collected at the bottom in a gutter, from there it runs by gravity to a 3,000 gallon water tank surrounded by three truckloads of stone in a bin. The water circulates about twice during a sunny day, getting hotter each time it goes across the roof. The water passes through a simple heat exchanger to warm the water for kitchen and baths and an indoor swimming pool. The thermostat in the living room turns on a 1/6 h.p. blower to pull chilly air down from the living quarters through the warm stones and around a warm tank of water and back again into the house. When extra heat is needed, an auxiliary oil furnace kicks on automatically.<sup>17</sup>

One of the most ambitious feasibility studies of solar power for the home is underway at the University of Delaware. The University is building an experimental single family home which will provide an occupant not only with thermal energy, but also with a small part of its electricity requirements. The home has forty collectors on its roof, each employing cadmium, sulphite, copper, and

<sup>16</sup> *Business Week*, May 19, 1973, p. 68.

<sup>17</sup> *The Washington Post*, December 23, 1973, p. G1 and G3.

solar cells to convert sunlight directly into electricity as well as absorbing the sun's heat to provide hot water.

In 1972 the General Services Administration (GSA) designated the new Federal Office Building in Saginaw, Mich., as an environmental demonstration building. It also designated the new Federal Office building in Manchester, N.H. as an energy conservation building. For the New Hampshire project the GSA made energy conservation a prime design parameter, to be considered along with function, fire safety, life cycle costs, and esthetics. The GSA sought help from schools of architecture and engineering, colleges and universities throughout the United States, technical societies, the GSA and other federal agencies. The National Bureau of Standards developed a series of computer studies designed to show the possibilities of savings through the control of the building orientation. The results of these efforts were available at the beginning of the design. The GSA expects the building to operate with at least 20 per cent less energy consumption than other comparable existing buildings. From this experiment the GSA hopes to be able to develop guidelines and criteria for use in the design and construction of future buildings. Solar collectors are to be used in both the Saginaw and Manchester energy demonstration buildings. In the Saginaw building the solar collector is expected to heat all the water and provide 70 per cent of the heating of the building.

The federal government is also experimenting in the construction of Social Security Administration program centers in Philadelphia, Chicago, and Richmond, Calif. It is hoped that this new approach may bring major building elements into one system that will minimize operating costs and improve services over the life of the building. Contract awards for the buildings were made not on the basis of first cost, but included consideration of the cost of energy consumed by the building over a forty year span. The savings thus involved amounted to a 23 per cent reduction in the air conditioning requirements for the typical office space.

Another interesting experiment in solar energy is the process used by the environmental quality laboratory at the California Institute of Technology. It has formed a coalition between local energy utility companies, building firms, and solar equipment manufacturers to demonstrate the feasibility of solar water heating in new apartment buildings constructed in southern California. The coalition estimates that gas consumption can be reduced by 80 per cent of present levels. The major obstacle to the use of solar water heating is that the building trade is one of the most conservative in America and power companies are naturally suspicious of any innovation that will reduce consumption of their product.

In early March 1974, a mobile high school classroom in Warrenton, Virginia was scheduled to be heated by solar energy in an experiment financed by the National Science Foundation (NSF). The shift to solar energy was expected to reduce substantially the heating bill for the classroom. The NSF was simultaneously financing other experiments in Minnesota, Massachusetts, and Maryland. All four systems were designed to augment existing heating systems rather than displace them. One of the experiments has been designed with significant heat storage facilities; its underground tanks should allow it to provide heat for five consecutive sunless days.<sup>18</sup>

Partly as a consequence of the spreading "energy crisis," and partly reflecting the growing interest in the search for alternative energy sources, a number of bills has been introduced into the House of Representatives to provide an income tax credit to homeowners who convert to solar heating and cooling.

Thus far, the discussion has centered on the uses of solar energy where the technology is fairly well known and where the uses could become commercial in a few years, but the big impact of solar energy is expected to be mainly in the field of making electricity. Three of these possibilities will now be discussed.

One proposal is by Dr. Peter E. Glaser, Vice-President and head of Engineering Sciences of Arthur D. Little and Co. of Cambridge, Mass. He insists that the satellite solar power station (SSPS) offers an opportunity to apply space technology for the benefit of mankind. With \$3.5 billion for R & D spread over the next fifteen years, the National Science Foundation and NASA estimate that power from the sun could economically provide 35 per cent of the energy required to heat and cool buildings by the year 2020. Glaser visualizes an SSPS

<sup>18</sup> See, for example, *The Washington Post*, February 2, 1974, p. E 42; and *H.R. 10952*, 93d Congress, 1st session, October 16, 1973.

in equatorial orbit. The SSPS would always face the sun and the antenna would direct microwave beams to a ground receiver. Glaser envisions that the satellite would circle the earth at a height of 22,000 miles. Solar collectors, a light weight collector of solar cells, would convert sunlight into electricity which could then be changed into microwave energy and beamed to the earth. There it could be collected on an antenna and converted back into electricity. Glaser calculated that a solar collector five miles by five miles and an antenna six miles by six miles would be needed for a ten thousand megawatt power station. The solar cells would have to be very thin to save weight and there is no telling how long it will take to develop them to the point where they could be mass produced. They are very expensive at the present time and have been used mainly in space work, but they are reliable. New methods of producing single silicone crystals on a mass production basis can drive the cost down sharply. It is currently about \$175 per kilowatt.

In the southwestern part of the United States there are at least two experiments currently being conducted to produce large amounts of electricity from solar energy by the use of modular reflectors. The difficulty with attempts to produce large amounts of electricity from solar energy is that, while the energy itself is free, the capital cost of the equipment is so relatively expensive that the electricity produced is so high that it is not economically feasible, given current prices. Additional experimental work is clearly called for. Many solar enthusiasts think that the capital and other costs can be substantially reduced.

The world's largest solar furnace has been built at Odeillo, France, in the Eastern Pyrenees mountains. It consists of a large, fixed parabolic mirror of more than 21,600 square feet, with 9,000 facets, and a furnace. The movable mirrors are equipped with control sights that guide them in following progression of the sun. Although this furnace is the world's largest and is ten times as powerful as its nearest rival in the United States, it is a reflection of current interest in the field. The fact that the Odeillo furnace cost a little more than \$7 million to construct and has an annual operating budget of \$125,000, is hardly a massive commitment on the part of France and almost a toy plaything in the United States.

Probably the most significant suggest that has come out of the Odeillo furnace operation concerns the economies of scale question. Most schemes so far advanced for converting solar energy into electricity have been conceived in terms of providing enough electricity to supply an entire city. But, the French maintain that when one doubles the size of a solar installation, one gets twice as much electricity at perhaps three times the cost. A joint NSF/NASA report concluded that the economies of scale we expect in conventional power stations will probably not be obtained where solar energy is concerned. In other words, small installations will be more economical. While this conclusion may be changed by further experiments, in the near future solar energy is likely to be used for heating and cooling houses and office buildings, rather than for the supply of electricity to large cities.

Nevertheless, solar enthusiasts, such as Dr. Werner von Braun, the famous rocket expert, in a message to the International Solar Energy Society in Paris, said that solar energy will be in the 1970's what space exploration was in the 1960's. Dr. von Braun is currently a vice president of Fairchild Space and Electronics Company.<sup>19</sup>

#### HYDROGEN

In recent years there has been a growing interest in hydrogen as a fuel for the world's growing needs. In the United States and in some thirty laboratories around the world researchers are working on various aspects of hydrogen as a fuel. It is being discussed at scientific meetings, and an expanding group of books and articles is appearing with titles such as "When Hydrogen Becomes the World's Chief Fuel."<sup>20</sup> Hydrogen is the lightest of all elements. Since it is found in enormous quantities in every body of water, it is one of the most abundant elements on the planet. When it is burned, it reverts to water. It is pollution free and a recyclable fuel. Hydrogen derived from nuclear or other forms of energy could supply all the demands commonly met today by fossil fuels. These demands include industrial, commercial, residential and vehicular power, as well as the local generation of electricity. There are no insuperable problems

<sup>19</sup> *The Washington Post*, December 9, 1973, p. G1.

<sup>20</sup> *Business Week*, Sept. 23, 1972, pp. 98-102.

in transmitting and distributing hydrogen when using it for domestic and commercial heating and cooking. Applying hydrogen as a vehicular and aircraft fuel depends more on solving tankage and transfer problems than it has to do with the engine.

It is easy to make hydrogen by passing an electric current through water, but such electrolysis is too expensive for the hydrogen economy. Reasonably inexpensive hydrogen for auto fuel and other direct applications might be made from coal which is far more abundant than natural gas. But ultimately it will be necessary either to reduce electrolysis costs sharply or to devise an economical way to "crack" water thermally.

A number of experiments in running autos on hydrogen have already been successfully made. Roger J. Schoeppl, who heads a research team at Oklahoma State University, has built several hydrogen powered engines and is now developing a conversion kit to modify existing autos to use hydrogen fuel. He points out that two entries in the recent URBAN VEHICLE DESIGN COMPETITION were powered by hydrogen. Each won in its category. France's Renault, working with the Institut Francais du Petrole and L'Air Liquide, is developing a car powered by hydrogen fuel cell. The group expected to have a prototype ready in 1973.<sup>21</sup> The researchers believe that such cars could be economically competitive in less than ten years. One of the difficulties with powering autos by hydrogen is the problem of the size of the tank, and work is now going on on metal hydrides which are solid compounds that decompose when they are heated to give off hydrogen gas. Researchers believe that it will require only three or four years of development and safety studies to make them usable.

One of the incidents that gave hydrogen a bad name was the German airship Hindenberg in 1937. A spark ignited the Hindenberg while it was landing in Lakehurst, New Jersey and the dirigible burst into a ball of fire. The blaze killed thirty-six of the ninety-seven passengers on board with the result that the reputation of hydrogen was tarnished. In April 1972 a dozen hydrogen experts formed the Hindenberg Society to dispel what they called the "Hindenberg syndrome."<sup>22</sup>

It costs a little more to transport energy in the form of hydrogen than to do so in the form of natural gas, according to Derek P. Gregory, assistant director for engineering research at the Institute of Gas Technology. But he is of the opinion that it is a lot cheaper than transmitting electricity, even with cryogenic cables. Furthermore, hydrogen can be stored easily for peak power periods.

The natural gas industry has well established the technology for moving energy in underground gas pipelines. Pipelining gas costs considerably less for an equal amount of energy than transmitting electric power. Pipelines made of the same materials as natural gas lines already carry industrial hydrogen short distances. For transmission over longer distances pipelines would need larger compressor stations than those now used for natural gas. Hydrogen is low in density, hence a given pipe can carry a greater volume of hydrogen than natural gas. According to Derek P. Gregory, it should be possible to produce hydrogen from nuclear or solar heat and deliver it to its point of use more cheaply than to produce electric energy and deliver that. Autos fueled by hydrogen give off no carbon monoxide or unburned hydrocarbons.

Although far more bulky than hydrocarbon fuels on an equal energy basis, hydrogen weighs only about one-third as much as kerosene. This is especially advantageous for high speed or long range aircraft where fuel weight dominates the aircraft design. Lockheed Aircraft Corporation, for example, has estimated that substituting hydrogen for kerosene would reduce the takeoff weight of an advanced supersonic transport plane from about 600,000 pounds to 400,000 pounds.

We already have much of the technology needed to put hydrogen to use. It needs further development, but it seems clear that the federal government should make a substantial input into this area.<sup>23</sup>

<sup>21</sup> *Business Week*, September 23, 1972, p. 101.

<sup>22</sup> *Ibid.*

<sup>23</sup> See: Wilson Clark, "Hydrogen may emerge as the master fuel to power a clean-air future," *Smithsonian*, August, 1972, pp. 13-18; W. E. Winsche, K. C. Hoffman, and F. J. Salzano, "Hydrogen: Its Future Role in the Nation's Energy Economy," *Science*, June 29, 1973, pp. 1325-1332; Lawrence W. Jones, "The hydrogen economy: an early retrospective," *Journal of Environmental Planning and Pollution Control*, Vol. 1, No. 3, 1973, pp. 12-22; Derek P. Gregory, "The Hydrogen Economy," *Scientific American*, January 1973, pp. 13-21; and Derek P. Gregory, "Hydrogen, Transportable, Storable Energy Medium," *Astronautics and Aeronautics*, August, 1973, pp. 38-43.

## WIND

Wind has long been used in the service of man. One of the oldest and most widespread uses of windpower was to drive sailing ships. In 1850 in America the use of windmills represented the equivalent of about 1.4 billion horsepower hours of work, but it fell to about half that in the next twenty years. But the American windmill industry thrived in America until the early 20th century. Wind ceased to be used in sailing ships when wind was replaced by the faster more dependable coal and oil burning vessels, although at the present time some new designs for ships that are powered mainly by wind are being undertaken in Britain and elsewhere.

Recently a NSF/NASA committee suggested that by the year 2000 a major American development in windpower could produce 1.5 trillion kilowatt hours of electricity, equivalent to the total electricity consumed in 1970 in the United States. Wind does not blow evenly and it is not uniform throughout the United States, but in some places it is more powerful than others. In home size power plants when the wind stops blowing, direct power storage is accomplished by charging batteries. In a larger system energy can be stored either mechanically or hydraulically by pumping water or air into a reservoir and then releasing it later to drive an engine operating an electric generator. Another device is the fly wheel, similar to a gyroscope. Still another technique is the production of synthetic fuel—hydrogen which can be produced by electrolysis of ordinary water. After electrolysis, the hydrogen is compressed and stored for high grade fuel. On the days when there is little or no wind, conventional fossil fuel power can be used.

If traditional fossil fuels increase in price as anticipated, William E. Heronemus, professor of Civil Engineering at the University of Massachusetts, has proposed a wide ranging network of huge wind generators in numerous U.S. locations to provide virtually all the nation's electricity. Heronemus believes that the power from an offshore system would be economically competitive with future conventional electric power costs in New England. The National Science Foundation is spending \$1.25 million in 1973-74 to assess the development of windpower. This is out of a total of \$872 million for energy research and development. Thus, wind power, properly developed with modern technology, can provide a partial answer to our energy shortage problems in some areas of the nation.<sup>24</sup>

## THE POTENTIAL OF PLASMA—MHD

Plasma is the fourth state of matter, different from solids, liquids and gases. About 50 miles or so in the ionosphere, the world of plasma begins. The upper layers of the air, called the ionosphere, are plasma. The sun is plasma and so are all the stars. In fact almost all the universe is plasma.

Plasma physics offers a way of producing electricity with very little pollution and with greater efficiency than present electric power generators. This is called magneto hydro dynamics (MHD). This is the interacting of moving plasma with a magnetic field. The MHD generator is simple. There are no moving parts. Only the plasma moves at supersonic speeds. The MHD generator is a pipe, called a channel, surrounded by a magnet. At one end of the channel is a heat source; at the other is an exhaust system. Electrodes inside the channel tap off the current that is being produced in the plasma. A big advantage of the MHD is that it is highly efficient and it is low in pollution. The best modern turbo generator power plants are about 40 per cent efficient. Nuclear power plants are less than that. The first MHD power plants will be between 50 and 60 per cent efficient. Later developments are expected to improve on that percentage. MHD generators operate at high temperatures, more than twice as high as turbines.

The controlled thermonuclear reactor (CTR) power plant may prove to be the ultimate recycling machine in the form of a fusion torch. The energy of the fusion plasma can be used to totally vaporize any material we wish to recycle. For example, an automobile can be reduced to a cloud of gas or plasma consisting of pure elements. While it is still in the gas phase, these elements can be separated from one another by conventional equipment now in existence, and

<sup>24</sup> See: Wilson Clark, *Smithsonian*, November 1973, pp. 70-71, 73-75, 77-78.

then recycled. Ben Bova, a consultant to industry and editor of *Analog* magazine, maintains that when it becomes operational, fusion will certainly be the biggest bargain since the discovery of fire. To date, since World War II, the United States has spent about \$400 million on fusion research. Russia spends about twice as much.<sup>25</sup>

Plasma holds the potential of another inexhaustible source of clean energy. But much work remains to be done. This is clearly another area where the federal government must pay most of the cost of development work.

#### THE POTENTIAL FROM GARBAGE BURNING

The United States produces an estimated 2½ billion tons of waste a year. If burned in power plants, this could produce more than half the electricity we are now generating. The idea of extracting high quality gas from garbage has been slow to catch on in the United States, although a few places have begun recently to try it on an experimental basis. This is being done in such faraway places as California, St. Louis, Missouri, and Connecticut but the process is still in its infancy. NRG Technology, Inc. in Los Angeles County, California is beginning an experiment with a landfill to produce natural gas. When the landfill is complete within five years, the site will be developed into a golf course and recreational park. There are an estimated 1,000 such landfills in the United States that meet the requirements for a gas recovery project, but actual gas recovery from a large fill has not been previously attempted.<sup>26</sup> Most cities seem content with the old fashioned method of dumping their waste farther and farther from the heart of the city. The only significant improvement in garbage disposal in centuries has been the design of more efficient trucks.

#### GOVERNMENT OWNED TVA-TYPE CORPORATIONS

The American people are not likely to put up with the energy shortage for another quarter of a century with all the uncertainty and inconvenience that this involves. Nor is there any need to wait so long. Important strides toward alleviating some of the shortages can be made by 1980 or sooner.

For the immediate future reliance must be placed on energy sources where the basic technology is currently known, or nearly so. The most fruitful sources seem to be offshore production of oil and gas, coal gasification and liquefaction, geothermal energy, oil shale, nuclear power and possibly the Canadian tar sands. These sources are in adequate supply to meet our needs for the indefinite future. Other sources on the horizon include solar energy, helium, and plasma. These sources should provide our energy needs for at least the next 10,000 years.

Offshore production of oil and gas needs nothing more than equipment and manpower. While it may require a year or two to step up output of offshore production significantly, that will help meet our needs. Coal, our most abundant source of fossil fuels, is available in adequate quantities now. While the technology of coal gasification and liquefaction will doubtless be improved in the future, enough is currently known to begin production.

The technology of geothermal energy has now been known for seven decades. In the United States one plant is now operating about 80 miles north of San Francisco. Others can be made operative in a few years.

It has been known for decades that there are several times as much shale oil in Colorado, Utah, and Wyoming as there is oil in the entire Middle East. This may well prove to be a substantially cheaper source of energy than current prices for crude oil and gas suggest.

Research and development expenditures on nuclear fusion should determine within the next decade or so whether this source is safe.

The Canadian tar sands contain about as much oil as the known deposits of the Middle East. While the Canadians may be counted on for some hard bargaining, most of the tar sands are owned by U.S. companies in cooperation with Canadian private capital and the Canadian government. Reasonable arrangements can be made now to begin production from the tar sands and some share of it can be reasonably expected to augment U.S. supplies.

<sup>25</sup> The above account relies heavily on Ben Bova, "Physicists probe the ultimate source of energy," *Smithsonian*, December 1972, pp. 38-44; see also Graham W. Howe, "Future Energy Sources . . . A Look at the Exotic," *Rural Electrification*, October, 1973, p. 16.

<sup>26</sup> *World Oil*, January 1974, p. 15.

In recent months Americans have begun to conserve oil and gas, although we still have a long way to go. The important thing is to see that only meaningful conservation measures are suggested, which will save significant amounts of gas and oil. Such measures as smaller cars that might be required to get at least 20 miles to a gallon of gas, public transportation, and car pooling seem to be reasonable. We must avoid the adoption of such hastily contrived measures as year round daylight saving time. Although experience will vary from one region of the country to another, there is no solid evidence that daylight saving time results in a significant, or any, overall saving in the use of electricity. Personal inconvenience seems to be the only characteristic on which most of the nation can agree.

Various proposals have been made by different groups to help solve the energy shortage. Some would nationalize the petroleum industry in whole or in part. Some would apply antitrust measures that will result in divesting the oil companies of different phases of the industry such as production, refining, transportation, or marketing. Others have proposed that the energy industry be declared a public utility so that prices and products would be controlled by the government. Most people are agreed that it is unlikely and undesirable to continue the present shortages.

The proposal made here is that the government establish a series of government owned corporations similar to the TVA. This action will be in line with our tradition and in line with worldwide trends. Many governments, not just communist and socialist governments, are taking a more important lead in determining energy policy. For those in the industry who shudder at the thought of any government activity, it should be borne in mind that the U. S. government is likely to play a more important role in the future than it has in the past, regardless of what we think. The federal government must take steps to make sure that the shortages which now exist are never repeated. The great bulk of the American people will, I think, support such measures. The policy they are most unlikely to support is one of doing nothing or taking only token measures.

The federal government already has a big stake in the energy business. It owns most of the offshore lands that will be leased in the future. It owns 80 per cent or more of the oil shale. It owns 80 per cent or more of the geothermal lands, mostly in the western part of the United States. It owns much of the coal deposits in the western part of the country. Furthermore, the federal government is a big consumer of energy both during war and peace. Other levels of government—state and local—are also big consumers of energy.

The federal government pays for a substantial portion of the R & D expenditures in such fields as nuclear energy, geothermal energy, solar energy, helium, plasma, shale oil, etc. In some of these areas the federal government sponsors research by private firms in whole or in part. In some areas the federal government participates with private firms. The federal government is already in the energy business in such areas as price control, regulation, allocation, and leasing of public lands. The federal government has been involved in the electric energy business through the TVA since 1935.

If the federal government gets involved in the energy business to the extent of 10–15 per cent of the industry, this will introduce an element of competition into an industry where noncompetitive practices have been a feature for most of its history. Furthermore, federal government participation in the industry will provide it with essential information on such important topics as costs, prices, supplies, etc. At the present time, the federal government must rely mainly on information provided by firms in the industry. This is unsatisfactory.

The figures in Tables 2 and 3 are intended to be illustrative only. The Congress may want to increase some of them and decrease others. It may also, as experience is gained, want to change the emphasis from one source to another because one source of energy looks more promising. No brief is held out for the figures. They have not been taken from the New Testament, the Old Testament, the Koran, or any other holy book. They are intended as rough guidelines to get the federal government somewhat more involved than it has been in the past. It is a modest proposal. In virtually every major country in the world, the central government plays a more important role, frequently a much more important role, than is here proposed for the United States Government.

It is proposed that the federal government become involved in the energy business to the extent of 20 to 30 per cent of the increase. By 1985 this will mean that the federal government will own 10 to 15 per cent of the industry.

We must never again let ourselves be put in the position of relying too heavily on one source of energy—oil and gas now provide 75 per cent of our energy—or on one area of the world. We are told over and over again, although not correctly, that most of the world's oil and gas are in the Middle East and North Africa. We must develop a variety of energy resources wherever they may happen to be. True international cooperation depends on our ability to recognize the interests of producing areas as well as consuming areas of the world.

In the years immediately ahead considerable experimentation must be undertaken in areas that are not routine, although a substantial technology exists in the United States and elsewhere. The federal government is in a position to take some of the risks involved, whereas private firms are understandably reluctant to do so. If the federal government undertakes these risks and establishes sensible environmental standards, private firms will be able to take over the remaining tasks with more assurance.

The TVA-type corporations suggested here will become self financing within a few years through the sale of their products at prevailing market prices. The costs of R. and D., as well as the substantial benefits, are to be shared by the nation. Projected expenditures on R and D are only a small fraction of 1 per cent of our gross national product. The benefits will be available to the entire world.

TABLE 2.—SUGGESTED FEDERAL EXPENDITURES ON RESEARCH AND DEVELOPMENT IN VARIOUS TYPES OF ENERGY, ANNUALLY, 1974-85

(Billions of 1972 dollars)

	Gross national product	Gross private domestic investment	Nuclear	Coal	Solar	Helium	Plasma	Geo- thermal	Total R. & D.
1955.....	\$646	\$112							
1960.....	717	107							
1968.....	1,039	153							
1972.....	1,155	178							
1973.....	1,218	189							
1974.....	1,280	200	\$1	\$1.0	\$0.5	\$0.3	\$0.4	\$0.3	\$3.5
1975.....	1,344	211	1	1.0	1.0	.4	.5	.3	4.2
1976.....	1,406	222	1	1.0	1.0	.5	.7	.3	4.5
1977.....	1,469	233	1	.5	1.0	.7	.8	.3	4.3
1978.....	1,532	244	1	.5	1.0	.8	1.0	.3	4.6
1979.....	1,595	255	1	.5	.5	1.0	1.0	.2	4.2
1980.....	1,658	266	1	.5	.5	1.0	1.0	.2	4.2
1981.....	1,715	275	1	.5	.5	1.0	1.0	.2	4.2
1982.....	1,772	283	1	.3	.4	1.0	1.0	.2	3.9
1983.....	1,828	292	1	.3	.4	1.0	1.0	.1	3.8
1984.....	1,885	300	1	.3	.3	1.0	1.0	.1	3.7
1985.....	1,942	309	1	.3	.3	1.0	1.0	.1	3.7

The data for gross national product and gross private domestic investment are taken from Ronald E. Kutscher, "The United States Economy in 1985 Projections of GNP, Incomes, Output, and Employment." *Monthly Labor Review*, December 1973, table 5, p. 34. The source shows data for 1955, 1960, 1968, and 1972, and projections for 1980 and 1985. Intermediate years, not shown in the source, were interpolated by the author, on a straight line basis. All figures have been rounded to the nearest billion.

Data on investment needs through 1985 vary widely and are to be considered as estimates only. The ones used for tables 2 and 3 are taken from Robert C. Holland, member, Board of Governors of the Federal Reserve System, speech before the financial conference, National Coal Association, Chicago, Ill., Oct. 31, 1973, "Public Policy Issues in the Financing of New Energy Capacity," p. 5. Other estimates are available from the National Petroleum Council. The American Petroleum Institute booklet summarizing testimony given before the Committee



on Ways and Means, U.S. House of Representatives on behalf of the American Petroleum Institute, by William I. Spencer, president, First National City Bank, March 19 1973, pp. 29-33; The Conference Board *Energy and Public Policy*—1972, Edwin L. Kennedy, "Future Energy Financing," pp. 179-181; Manufacturers Hanover Trust, "Economic Report: Financial Implications of Material Shortages," by Tilford Gaines, November 1973; Exxon SA, statement by John Winger, "Where's the Money to Come From?" Third Quarter, 1973, pp. 28, ff; and Warren B. Davis, director, energy economics, Gulf Oil Corp., "Petroleum's Role in Meeting Future Energy Needs of the World," paper presented at the summer energy seminar of the Japan Institute of Energy Economics, September 25, 1973, p. 11. There are many others.

The amounts suggested for federal spending on nuclear, coal, solar, helium, plasma, and geothermal are suggested by the author. The amount now budgeted for nuclear is close to the amounts suggested, although there is a slight increase. If the amounts suggested are spent, it should be possible to determine by 1985 if these plants are safe. The amounts suggested for coal gasification and liquefaction fall off sharply after 1976, because it is felt that so much work has been done in the United States and other countries that it will not be necessary to continue R and D spending at the high levels suggested for the next three years. The amounts suggested for solar energy are in line with other suggestions that have been made. Helium can in a sense be considered an exotic source of energy. Hence, R and D spending starts out relatively small and increases to \$1.0 billion in 1979 and is continued at that level through 1985. Spending on plasma research is a relatively long range project and will probably need to be continued after 1985. Spending on research on geothermal is maintained at relatively low levels throughout because so much is already known about this source both in the United States and in many countries of the world. If the amounts suggested turn out to be too small, they can be raised.

Although the amounts suggested for R and D are in a sense arbitrary, they are generally in line with figures suggested in various Congressional hearings, amounts suggested in scientific papers and by team investigators. It will be noted that the amounts vary from \$3.5 billion to \$4.6 billion through 1985.

TABLE 3.—SUGGESTED FEDERAL EXPENDITURES IN VARIOUS TYPES OF ENERGY PRODUCTION AND VARIOUS PHASES OF ENERGY PRODUCTION, ANNUALLY, 1974-85

	(Billions of 1972 dollars)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Gross private domestic investment	Total investment in energy	Potential federal investment	Federal Government R. & D.	Other potential Federal Government	Off-shore	Coal	Geo-thermal
1974 .....	\$200	\$50	\$15	\$3.5	11.5	\$0.3	\$0.3	\$0.3
1975 .....	211	53	16	4.2	11.8	.5	.5	.5
1976 .....	222	55	17	4.5	12.5	.7	1.0	1.0
1977 .....	233	58	17	4.3	12.7	1.0	1.0	1.0
1978 .....	244	59	18	4.6	13.4	1.2	1.2	1.0
1979 .....	255	63	19	4.2	14.8	1.5	1.5	1.2
1980 .....	266	66	19	4.2	14.8	1.5	1.5	1.3
1981 .....	275	69	20	4.2	15.8	1.5	1.5	1.3
1982 .....	283	71	21	3.9	17.1	1.5	1.5	1.3
1983 .....	292	74	22	3.8	18.2	1.5	1.6	1.4
1984 .....	300	75	22	3.7	18.3	1.6	1.7	1.5
1985 .....	309	77	23	3.7	19.3	1.7	1.8	1.6

Note. The figures on gross private domestic investment (column 1) are those shown in table 2.

Figures on total investment in energy (column 2) are based on the assumption that investment in energy through 1985 will be 25 percent of total investment. In recent years this investment has been about 21 percent. Some estimates place investment in energy as high as 30 percent of total gross private domestic investment. We have assumed a middle position.

Potential Federal investment (column 3) is assumed to be 30 percent of total investment in energy, rounded to the nearest billion dollars. If the Federal Government invests this amount, by 1985 the Federal Government should have about 10 to 15 percent of the energy business in the United States. (Column 4.) The figures on Federal Government spending on R. & D. are taken from Table 2.

Other potential Federal Government expenditures (column 5) are the differences between Federal investment and Federal spending on R. & D. (column 3 minus column 4).

TABLE 3.—SUGGESTED FEDERAL EXPENDITURES IN VARIOUS TYPES OF ENERGY PRODUCTION AND VARIOUS PHASES OF ENERGY PRODUCTION, ANNUALLY, 1974-85—Continued

(Billions of 1972 dollars)

	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
	Shale	Solar	Helium	Pipelines	Refineries	Marketing	Superports	Total
1974.....	\$0.4	\$0.3	\$0.3	\$0.2	\$0.4	\$0.3	\$0.2	\$3.1
1975.....	.6	.5	.4	.5	.5	.5	.3	4.8
1976.....	1.0	1.0	.7	1.0	1.0	.7	.3	8.4
1977.....	1.0	1.0	1.0	1.0	1.0	1.0	.3	9.3
1978.....	1.2	1.0	1.0	1.0	.9	.9	.3	9.7
1979.....	1.5	1.0	1.0	1.1	.9	.9	.3	10.9
1980.....	1.5	1.0	1.0	1.1	.8	.8	.3	10.8
1981.....	1.5	1.0	1.0	1.1	.8	.8	.3	10.8
1982.....	1.5	1.0	1.0	1.1	.8	.8	.3	10.8
1983.....	1.6	1.0	1.0	1.1	.8	.8	.3	11.1
1984.....	1.8	1.0	1.0	1.1	.8	.8	.3	11.6
1985.....	2.0	1.0	1.0	1.1	.8	.8	.3	12.1

## CONCLUDING COMMENT

In the preceding pages of this report and in an earlier report has been made to assess our energy resources. One conclusion emerges loud and clear. The United States is not energy bankrupt and there is no reason to believe that we will become energy bankrupt in the future. Enough energy is available from traditional sources to meet our present and prospective needs far into the future. There are no realistic grounds for pessimism.

It may require a few years to develop some of our resources and a longer time to develop others. But, energy is so important to our economy that vigorous action is called for immediately. We must take steps now to make sure that the present shortage never again happens. Fortunately we can.

Chairman HUMPHREY. Thank you very much gentlemen. You will pardon me if I seem impolite, but I must charge off to a vote. Thank you.

[Whereupon, at 12:50 p.m., the committee adjourned, subject to the call of the Chair.]