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Whither Energy – Future Shock or Greening?

KENNETH C. HOFFMAN

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MASTER

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INTRODUCTION

Dr. Kenneth C. Hoffman is a distinguished member of the Department staff. Let me trace for you a few elements in his career. He is that rarity among us, a genuine native-born New Yorker. In our Department we like to have one of everything, and we are very proud to present him as our native-born citizen. Ken did his undergraduate study at New York University, graduating in 1954 as a Mechanical Engineer and then working as a Manufacturing Engineer at Grumman Aircraft Engineering Company. We are glad that he came away from there or he might be making space platforms or whatever today. He then spent a couple of years in the Air Force as an intelligence officer working in the area of mathematical analyses and using computers. He came to Brookhaven in 1956 and joined the Mechanical Engineering Division – that section assigned to what was then the Nuclear Engineering Department and is now the Department of Applied Science.

Here he worked on the 4-in. liquid uranium bismuth facility that we constructed in support of the liquid metal fuel reactor program, and had project engineering responsibility for an assortment of liquid metal heat transfer and corrosion facilities. He worked on the rotating fluidized bed scheme, the ordered bed scheme, conversion of the graphite reactor to study the conversion for high flux irradiation, and he had project engineering responsibility for Ray Davis's neutrino experiment in the Homestake mine in South Dakota.

In 1966 Ken became chief engineer of the pulsed fast reactor project, a scheme we worked on for some years in hopes that it would follow the high flux beam reactor as our next major facility in neutron research. That project aborted in the dark days of 1969-70 when most of the rest of the reactor work at BNL was phased out. Ken was one of the small band of survivors in the Engineering Division of the Department who worked on a variety of projects: space propulsion activities and alternative synthetic fuels were elements of the program that we lived on in those days. We even designed vessels for the Office of Saline Water. Ken became Head of the Engineering Assistance Group in 1971, Associate Head of the Division in 1972, and Head of the Division in 1973.

In 1965 he went back to school on a part-time basis, got a Master's Degree in applied mathematics at Adelphi in 1968, and entered the doctoral program in systems engineering at the Polytechnic Institute of Brooklyn, where he received a doctorate in 1972. His thesis work on the synthesis and development of the computer codes for a method of analysis of energy systems, called "Reference Energy System," has provided the basis for much of his work extending on to the present day. That Reference Energy System, with its many modifications, improvements, additions, and parallel efforts, has become a basic analysis tool of great importance in the present scheme of things. The systems were used in an assessment study performed for the Office of Science and Technology in 1972, for Dixie Lee Ray's analysis of the energy picture in 1973, for the Atomic Energy Commission, and subsequently in ERDA plans for their full programs. Today Ken is the Associate Chairman for Energy Programs in the Department, Head of the National Center for Analysis of Energy Systems, and a man with very diverse responsibilities and activities. He is a world recognized authority in energy systems analysis. Indeed, I regard his view as one of the most authoritative and well balanced of all of the current views of energy systems that we have. I even take his advice from time to time – I think that much of it. He has extensive contacts with the International Energy Agency activities and the Commission of the European Communities Energy Sections; he is on panels and workshops for the National Academy of Engineering; and he has close contact with the International Institute for Applied Systems Analysis in Austria.

We are just delighted to have him here this evening to talk about energy. Ken, it's a great pleasure.

J.M. Hendrie

ABSTRACT

The United States stands on the threshold of new energy policies, which will determine the future course of energy supply and demand. It is clear at this point that we must accommodate our society over the next 30 years to reduced supplies of oil and gas and to higher energy costs. This transition poses a challenge to our ingenuity, patience, and perseverance. Some see a very close relationship between energy use and national income, or GNP, and are not very hopeful for a future of reduced energy supply. Others see the decisions and choices that are forced on us by recent crises and by the longer-term realities as leading to an improved and more sustainable society where resources are used frugally and the air is pure.

Analysis of the energy system and its relationship to the economy and environment has led to several findings that give promise for the future. Given some lead time, our economy can accommodate to increased energy scarcity while delivering the goods and services that we desire for ourselves and for our descendants. Technology will play an extremely important role in our efforts to produce continued innovation, with perhaps more emphasis placed on the effective use of energy and resources in serving society – conservation.

There are still several difficult problems to be overcome during this transition period with regard to the distribution of energy use among various income groups in the U.S. and among the developed, developing, and less developed countries of the world. The management of this transition to new energy sources and a more efficient economy will require close coordination of energy policy with other domestic policies and with foreign policy to ensure that social strains and international tensions resulting from energy supply and trade problems do not get out of control.

The lecture will address these policy relationships and will include some projections of our energy future on regional, national, and international levels.

Whither Energy – Future Shock or Greening?

INTRODUCTION

The United States is now involved in the formulation of a comprehensive energy policy. At this point in the history of our nation, I think it is time to pause for a very close look at this process of policy formulation. When a country with the economic power and international presence of the United States makes policy in almost any area, it is indeed time for the rest of the world to watch and for all of us to participate. Hopefully, these policies will lead us to a successful energy future. The need for a comprehensive energy policy has been made quite clear by recent developments – the cold weather, the shortage of oil and gas, and the embargoes of a few years ago when we were quite short of oil and had to wait on long gasoline lines. Even more convincing is the realization that these were not short-term problems that are now behind us. These are, indeed, warnings of much more serious problems that lie ahead, and unless we really do something about them, we are going to have a very difficult time indeed.

The future structure of our society and our energy system will be determined largely by the policies that are formulated. Our policies have a significant impact on development throughout the world, since there is a close interrelationship between our economy and those of the rest of the world. The basic problems that concern us in the long term are, first, the fact that we are running very short and will eventually run out of conventional oil and gas as we now know them. We will need to substitute other energy forms for the oil and gas we now rely upon so heavily.

Another aspect of the problem is the fact that the alternatives now apparent to us for the near term have some associated environmental problems that seem to block our willingness to make large commitments and get on with the job of substituting these for oil and gas. So, in this conflict between technical and environmental problems, it becomes quite clear that trade offs will be required and that these are going to be some of the most difficult choices our nation will have to make. We should be hopeful that our policy will be flexible and adaptive because there are many uncertainties that we now face. None of us really know how much of any particular resource there is under the ground, or what the future development of our society and life-styles is likely to be. So our policies will have to be adaptive and evolve as we learn more about some of these uncertain factors.

Over the past few years we have gone through three stages in the evolution of our energy-related policies. As recently as five or ten years ago, the emphasis was on the use of energy for economic development and the recognition that we had to keep the price of energy low to encourage that development. We then became aware that large-scale energy use was damaging to the environment; and as energy activities were growing and making a significant negative contribution to the quality of the environment, we felt we could devote some of our national wealth to protection of the environment. So we began to set in motion a series of policies that made energy activities more expensive but had the desirable benefit of environmental protection. More recently, as a result of the embargo of 1973, we decided that energy self-sufficiency was the overriding concern, and Project Independence, that ill-fated move to become independent of foreign sources of energy by 1980 or 1985, was launched. We now have learned that complete energy independence is indeed very difficult to achieve. At the time that Project Independence was initiated, the U.S. was importing about one-third of the oil that it consumed. We are now importing close to one-half. So it has become quite clear that it is going to be very difficult for us to cut loose from the rest of the world and become self-sufficient. Nevertheless, it is necessary to drive hard at all these goals. We want to obtain energy at the lowest possible price. We want to protect the environment. We want to be as self-sufficient as possible so that we can maintain some flexibility in our foreign policies and not have them dictated by those who control the resources. These represent the complexities that we face in formulating an energy policy; we will be required to make very serious and detailed trade offs among these usually contradictory objectives. To some extent, these contradictions are resolved by decisions based on analyses of the trade offs and the costs and advantages of such trade offs. To an even greater extent, policy is determined in the political arena where the political interests of the various groups concerned, both within the U.S. and outside, come to bear.

The complexities that we face do not only involve objectives, but also the physical structure of the energy system and the way energy is used in our society. In our work at the National Center for Analysis of Energy Systems at Brookhaven, we began our policy analysis by looking at energy technologies, but quickly found it necessary to broaden that view. To deal sensibly with energy, it is necessary to understand how it is used in the economy. Energy is used not just for the sake of using it, but for the services it provides. It is used for the comfort, the mobility, and the employment that it provides our society. So the economic dimension of energy becomes very important. The environmental dimension that I have referred to is also important, but I won't say too much about that at this time. That subject was covered very well by Leonard Hamilton in a previous lecture. The National Center for Analysis of Energy Systems here at Brookhaven does address the energy problem in this broad scope, reflecting the technological, economic, environmental, and social aspects of energy in its analysis. Much of the work that I shall describe this evening has been done by the men and women in the Center.

THE ECONOMIC CONTEXT

I think it is useful to introduce the discussion of energy policy analysis by repeating that it is the

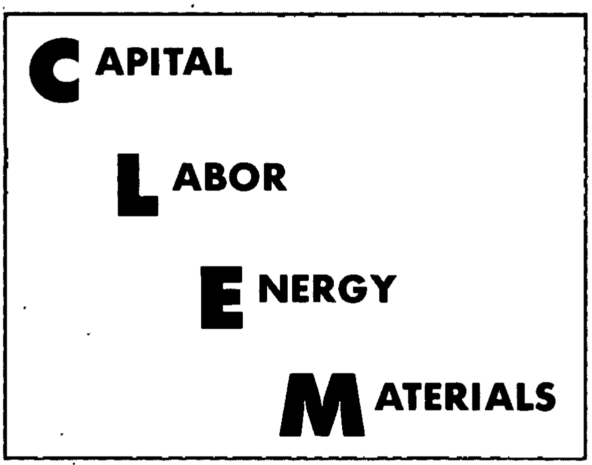

Figure 1. Inputs to the gross national product of the economy.

objective of our energy system to provide comfort, mobility, and employment. First, we need to understand how our economy functions and how our wealth is produced. Figure 1 indicates the inputs of capital, labor, energy, and materials that are required to produce goods or services. In order to produce a gross national product of a given level, which is a measure of the income and the physical consumption of goods and services that we enjoy, we need to employ all these factors of production. The capital input really represents deferred consumption. Instead of using labor, energy, and materials today to produce goods and services that we can enjoy immediately, we invest these inputs in building equipment and facilities that, although they will not produce an immediate return, will in the future produce a more abundant return of goods and services to society.

In general, the attention of economists and analysts is focused on what appears to be the scarce input at any particular time in history that threatens economic development. At one time, labor was viewed as the scarce input and in order for the economy to grow everyone had to work long hours. That led to the labor theory of value in economic history. We now have removed labor really as the limiting factor in our input to the economy, and it is beginning to be recognized that energy may be limiting input. So, it is not surprising that a lot of the economic analysis has shifted to energy and its role in producing the goods and services that make up the gross national product. I think we will find that it is really materials in general, our national resources, that we are using at a very high rate of consumption, that are likely to be the next limiting factor. We will then have to broaden our view from that of energy alone to include all the resources that we use to maintain the physical level of consumption and the life-style that we now enjoy.

When we look at the role of energy in producing gross national product, we find that in dollar terms energy accounts for only 5% of the gross national product. Now, the future shock side of the story is that for the past twenty years the amount of energy used and our GNP have been very closely linked. There has been roughly a one-to-one correspondence between energy and GNP, and the future shock will come if we suffer energy shortages and a resulting decline in our gross national product and our physical standard of living. The greening side of the picture is that this fixed relationship is one that exists really only in the short run. We saw last winter that, when we ran short of energy, factories had to be closed and people were out of jobs; but the greening side is that, in the long run, this energy-GNP ratio can be quite flexible and we can achieve economic growth with less energy input than we use now, through strong conservation efforts. These conservation efforts will involve simple leak plugging. We, indeed, waste quite a bit of energy. There is also some belt tightening that can be done. We can do with less of some of the services we now enjoy without really suffering a deterioration in our standard of living. The third, and toughest adjustment, will be the life-style change where, instead of engaging in very energy-intensive activities, we spend our money and our wealth on some of the less energy-intensive activities. Some of this change will be induced voluntarily through higher prices of energy resulting from scarcity. Some change can be induced by government policy through taxing energy and imposing a reallocation of expenditures into less energy-intensive activities. So there are indeed these two sides to the picture. Some see in the greening picture (the more flexible energy-GNP relationship) a very different life-style from that we now have; many see this as being desirable, in that we need to reduce our level of physical consumption and damage to the ecosystem. Others see it as quite undesirable, in that we have made a lot of social progress through increased energy use. We still have not solved the problem of providing equal opportunity and an equal standard of living for all our population, and we need to do much

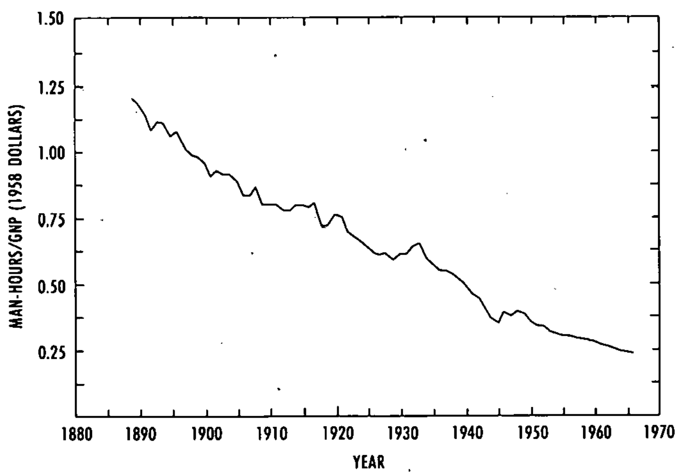

Figure 2. Trend of labor productivity in the United States.

more to produce more goods and services. So, this future shock vs greening view is laden with value judgments about where, indeed, society is heading and where it should be heading. These value judgments permeate energy policy.

In Figure 2 I have indicated how we have progressed from an era of scarcity to one of surplus with respect to one of the other inputs to our economy, labor. Over a period of about 70 years there has been a significant decline in the amount of labor that must be expended to produce a dollar's worth of gross national product, i.e., a dollar's worth of goods and services that we purchase as final consumers. Most of this improvement has come through technological change and, indeed, through the increased use of energy to provide these goods and services. The energy that has been used to replace labor is of a convenient form, e.g., oil and gas rather than coal, wood, and other energy forms that are more difficult to acquire and to use. At the turn of the century labor was viewed, as indicated earlier, as a constraining element in social development. We were employing children, and child labor laws had to be written to prevent that exploitation. Labor, indeed, was the scarce resource and the controlling factor in the economy. Through the use of energy and improved technology, we now have a labor surplus and the opposite problem of having more employable people in our society than are needed to produce the goods and services that we want. So, we have gone from one extreme with respect to labor to the other. The question is, can we bring about this same evolution in the use of energy through technological improvement and through changes in the structure of the economy?

Figure 3 shows a similar productivity curve for energy. This plots the ratio of the amount of energy in millions of Btu (it takes about 8 gal of gasoline to provide a million Btu) to GNP measured in 1958 dollars as a function of time. The ratio then is the amount of energy needed to produce a dollar's worth of GNP, or of goods and services for the final consumer. This is measured in constant dollars, so that the effect of inflation is wiped out. It is interesting to imagine the concerns that people must have had back in the period 1900-1910 as they were using wood, whale oil, and other resources in ever-increasing amounts while the energy-GNP ratio was increasing. It took more and more energy to produce a dollar's worth of goods and services. You can imagine the kind of concerns and feelings of crisis that must have existed then. People really wondered how we would ever develop further with the energy sources that were available at that time.

Then you see this tremendous decline. It is actually somewhat exaggerated on that curve because the zero is suppressed. The lowest level is about 0.08 million Btu per 1958 dollar. So, we are not really going down close to zero, but are approaching that level. Obviously, there was a significant decrease in the amount of energy needed to produce the same goods and services. Much of this decrease over that time period again came through technological change. It was a time of innovation and change in energy supply technologies. Coal was being used more efficiently in steam engines for propulsion and for electric power generation. The period was dominated by improvements of that type in the energy supply system. However, from roughly 1954 to the present time, if we compare the changes made during this era to some of the changes in the past, the amount of energy required to produce a dollar's worth of GNP has been relatively constant. There have been some wiggles, but really we are now at about the same point in the effectiveness of our use of energy as we were in 1954. In the future, we hope for significant improvement in that energy-GNP ratio, and this, of course, will be a very important objective of the policies that are developed.

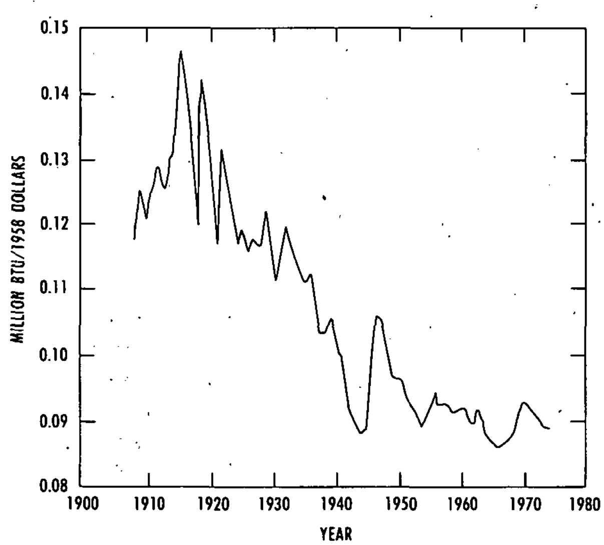

Figure 3. Trend of energy consumption per unit of GNP in the United States.

TECHNOLOGICAL FACTORS

Let me now address the technological side of the story, as illustrated in the Reference Energy System shown in Figure 4. This diagram represents the technical structure of the energy system and the flows throughout that system in 1972. I will later show you some projections to the year 2000 that have been developed recently. The Reference Energy System shows the flow of energy through the energy system starting with resources at the left-hand side to the end use of energy at the right-hand side. The functions for which we use energy – heating of homes, air conditioning, heating in industry, production of petrochemicals for plastics, travel – are the services we really desire from energy. We start the development of an energy forecast by looking at what services will be needed in the future, and then working back through the system and trying to figure out how we will supply those services, using the energy resources and technologies that are available. The units of energy consumption in these projections are quads. A quad, as you all know, is equal to one quadrillion, or 10^{15}, Btu. The energy consumption in 1972 indicated on the lower left-hand corner of Figure 4 was 72 quads. Vance Sailor once calculated how much that would amount to in physical terms if all that energy were in the form of coal; it would cover Manhattan Island to a depth of about sixteen feet.

The Reference Energy System indicates one of the basic energy problems that we are now faced with. If you look at the right-hand side, towards the lower part of the diagram, you will see the transportation system indicated. For that system we are totally dependent on liquid fuels that are produced now from crude oil. We do show, for the future, some paths that would allow the production of those liquid fuels from coal or from other sources, but right now we are totally limited to liquid fuels from crude oil as the source of energy for our transportation system. That is a basic problem that will have to be overcome by substituting synthetic liquid fuels derived from coal, shale oil, or biomass for the crude oil that we now use.

ENERGY PROJECTIONS

Let me start on the right-hand side of the Reference Energy System diagram and give a view of some of our projections of energy services. We do

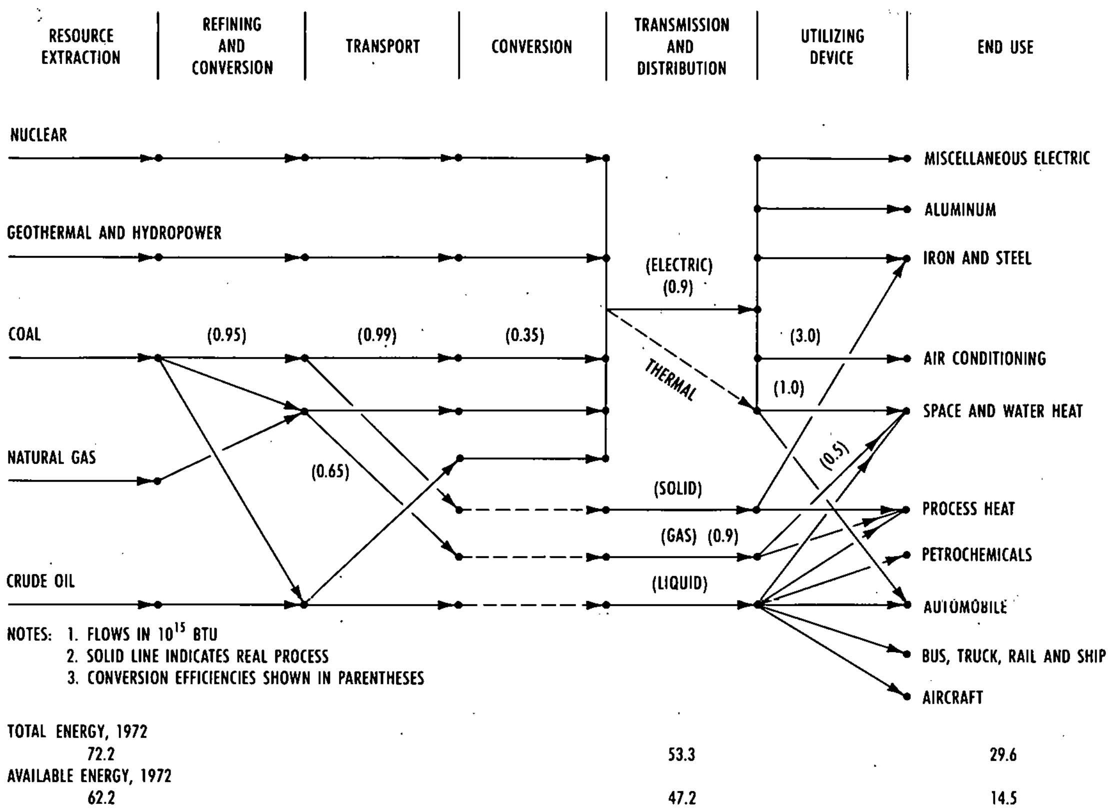

Figure 4. Reference energy system.

have to provide for the comfort, mobility, and employment of a growing population. We are using, in this case, a population projection based on the current low birth rates of around 260 million people in the year 2000. The family size, or the number of people per dwelling, is going down. This leads to the set of projections for the number of dwellings to be heated, cooled, and constructed; to projections of commercial floor space that will be required; and to projections of travel by different modes. All of these imply increased demands for energy services by the year 2000 which are summarized in Table 1. Depending on how efficiently we use our resources, these demands for services will determine the requirement for energy resources. If we become more efficient, if the energy-GNP ratio continues to go down as it did until twenty years ago, we will be able to provide these services with less energy than we would project on a straight extrapolation of the current energy-GNP ratio. This is the basis of the analysis, which is performed in a consistent way with an

Table 1

Projections of Energy Services*

	1972	2000
Population (10^6)	208.8	260
Dwellings (10^6), total	67	100
Single family	46	50
2 to 4 units	11	15
Multifamily	10	35
Commercial space (10^9 ft^2)	23.4	42
Auto vehicle miles (10^9)	986.4	2000
Air passenger miles (10^9)	169	680
Bus passenger miles (10^9)	89	161
Truck ton miles (10^9)	466	1040
Aluminum (10^9 lb), total	10.1	42.2
Primary	8.2	28.2
Scrap	1.9	13.9
Cement (10^6 bbl of 376 lb)	412	1021
Iron (10^9 obs)	169	306
Petrochemicals (ratio to 1972)	1	2.5

*Source: *Sourcebook for Energy Assessment,* M. Beller, Editor, BNL 50483, Dec. 1975.

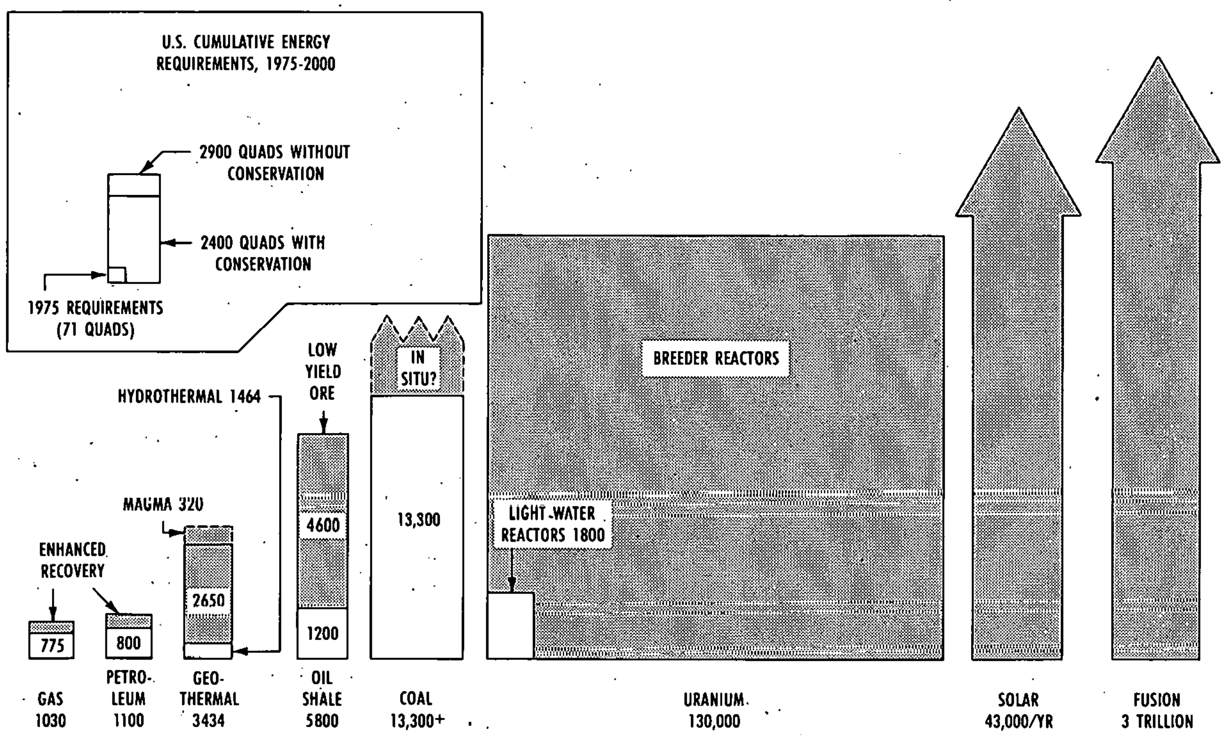

Figure 5. Resources base for the United States.

estimate of the GNP of the economy and the number of people that will demand services in our future society. Economic models are also employed to estimate the effect of policies on the energy-economic relationship.

We then look at the resources we have for this job, and the problem becomes quite clear. Figure 5 indicates the resource estimates used by ERDA as the basis for R&D planning. It must be pointed out that there is a large amount of uncertainty regarding resource estimates, and these have been chosen as a "prudent basis for planning." We may, indeed, "win the lottery" in terms of some new discovery, but it would not be prudent to count on that, given the serious economic consequences that we will face if energy is not available. In the upper left-hand corner of Figure 5 is a box that indicates the quantity of energy that will be required between 1970 and the year 2000, with some allowance for a moderate level of conservation. These projections were based on people's willingness to conserve energy voluntarily. If we employ mandatory conservation policies or marginal cost pricing of energy, I believe we can do quite a bit better than that. But the diagram does indicate that a significant amount of energy will be consumed between now and the year 2000.

The resource survey begins with gas and oil, which we find will probably be seriously depleted near the turn of the century or shortly thereafter. We really do not have enough oil and gas to rely on and use the way that we are using these resources now, and clearly our energy use patterns must change. We do have a good bit of geothermal energy. Of course, that is limited to the production of electricity or of heat that can be used near the source, and it is available only in certain regions of the United States. We also have extensive resources of oil shale, but it is more expensive than the oil that we now use. It is kind of a toss-up now whether oil will be produced at lower cost from shale or from coal. We do have lots of coal. Some of it is easily strip mined and can be obtained at fairly low cost but with some environmental damage. More of it is located in deeper seams where it is difficult to reach and where recovery is very labor intensive. Nevertheless, coal represents a large resource that will be a mainstay of our future energy system. The uranium picture is illustrated in the next block, indicating the amount of energy that we could get from the light water reactors now in existence which utilize uranium-235, with some conversion of uranium-238. You can see that the breeder reactor opens up a tremendous expansion in that resource, and really the amount of energy available there dominates all the other energy sources. There is, of course, a lot of solar energy and energy from nuclear fusion if it proves feasible and practical. That is a summary of the resources that we can draw on. The question is which shall we rely on, what will the environmental standards be, and how serious will we be about protecting ourselves against the environmental problems associated with some of these alternative sources?

Figure 6 shows some energy projections to the year 2000. These go back to 1950 and through to the present time in the solid line; then we pick up with our projections in the dashed lines. This diagram shows a plot of energy use on an annual basis, i.e., the number of Btu or quads used per year against time. You can see that in the last few years there has been a decline in the use of energy. This can be very misleading and many people believe that this trend will continue. They also conclude that we really do not need any new energy sources, and we do not need to worry about building new plants; we have had this decline and may need a little more energy but we won't go back up to the old level. Such circumstances are not unique in history. If you look back to around 1955, you see another dip in energy demand. It is not quite as deep, but that was a period of economic recession; and it is well known that, in the short run during a recession, energy use does follow the gross national product quite closely. So, as the GNP went down, energy use went down. We have seen those dips in history; we understand and can explain them. Let us hope that our economy does recover vigorously, and that we do not have to rely on low economic growth to solve our energy problems. Our policy should be designed to allow economic growth and development of our society while minimizing the use of energy required to attain that growth. According to our projections, such circumstances do require that more energy be developed and used.

If we plot the historical growth trend, it was somewhere around 3 to 3½%/yr and you can see that that would lead to a significant amount of energy use by the year 2000, probably in excess of 180 quads. From 1950 until about 1972 or 1973, energy prices decreased relative to the prices of other goods. Energy thus became more and more of a bargain and this really accounts for why the use of it did grow rather rapidly at the same rate as the GNP. We project that energy will be more expensive relative to other goods in the future and that this will cause a reduction in the growth rate of energy consumption relative to GNP. Our best guess is a reduction in that growth rate to something around 2%/yr through the year 2000 with GNP growing at around 3.0%/yr. There is a lower

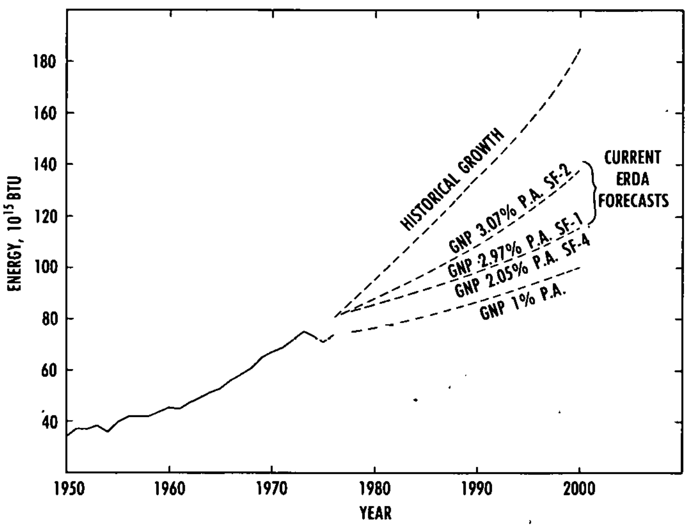

Figure 6. Energy forecasts to the year 2000. GNP rates are for 1985-2000 period. Energy consumption for SF-1 (conservation case) is similar to that in SF-4 (high fuel prices case).

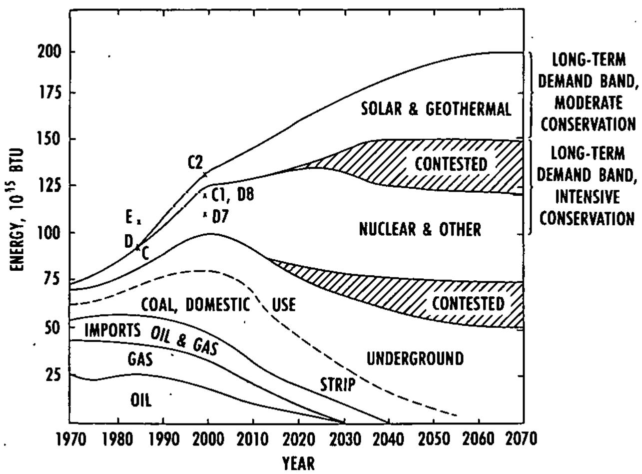

Figure 7. U.S. long-term energy supply.

projection indicated, the lower curve, where it is assumed that GNP growth is reduced, and of course that leads to even lower projections of energy consumption. We believe that these projections bracket the future growth trends. The two middle projections labeled *Current Forecasts* have a slightly different mix of policy assumptions but do correspond to about 3% annual GNP growth, and roughly between 1.9 and 2.1%/yr growth in energy demand.

We really must look past the year 2000, however, to see the real energy problems that we face. In Figure 7, we have a view of one of those projections worked on out past the year 2000. Now, we do not show energy growth continuing to escalate indefinitely here, even at the reduced rate of 2%/yr. There will be some saturation eventually, particularly if we arrive at a level population for a period of time. To satisfy thc asymptotic demand of 150 quads, we start building up the supply picture with oil and gas, then imports, and then on through coal and nuclear and solar energy. The top line, again, shows quads of energy consumption vs time. But now the projection goes to the year 2070, to take a longer view past the exhaustion of some of these resources. We cannot really say what society will be like that far in the future, but we can plot some reasonable curves for the life cycle or exhaustion cycle of particular resources. It becomes clear, from this analysis and from other analyses supporting this conclusion, that domestic oil production has reached a peak and is in the process of a long decline, and that we will effectively run out of economical sources by the year 2020 or 2030. Now, there are some who see that decline occurring much sooner and more precipitously and predict that the sources may run out by the year 2010 or 2015; but I have a feeling that a longer decay curve like this is a more reasonable assumption (with gas in short supply at the same time).

The next category of supply in the long-term picture is labeled *imports*. We use imported oil to fill the gap between the oil we produce domestically and that required to run our economy. This import curve is based on several analyses and shows that world production of oil will peak around 1980. I believe that it is impossible to overstate the importance of that peak. We have a situation at the present time where several oil-producing countries are running below their production capacity. They are acting to stretch out their reserves. Several have indicated that they are going to place limits on production, perhaps 20 or 30% above current production levels. Further, we are competing with the other major importing nations and regions, Europe and Japan, for that world production.

Table 2

Appropriate Energy Forms
for Specific Uses in Long Term

Heating & cooling	Solar energy with oil backup Off-peak electricity Synthetic oil & gas Waste heat
Electric generation	Coal Nuclear Geothermal Hydro and wind
Industry process heat and direct heat	By-product heat from electric cogeneration Solar energy Coal – via low Btu gas and direct combustion
Chemicals and petrochemicals	Coal Solar – wood
Transport	
Ground	Electric Synthetic liquids from coal biomass
Air	Synthetic liquids from coal

When the time comes that no further increase in oil supply is possible, either because of production ceilings or because we are unable to find and develop more oil, then tremendous international tension and problems are sure to result. Nations will begin to suffer severe economic strain if they have not planned ahead to accommodate to that kind of downturn in oil supply. Thus, an unforeseen or unplanned-for peak in world oil production can lead to tremendous suffering and international tension. As I said before, it is hard to overstate the consequences of this peak in world oil production.

It is very interesting to test an energy policy by projecting its long-term effects. We must ask whether the policies are consistent with long-term objectives of replacing conventional oil and gas with substitutes. We adopted the mechanism of looking out past the point of depletion of oil and gas resources.

Table 2 gives our best view of the appropriate mix of technologies and resources that will be used to satisfy our energy needs in the very long term. For heating and cooling buildings, we see a mix of technologies and resources that will be appropriate to different regions of the country. In some regions, solar energy will be very important and play a big role. Electricity, particularly off-peak electricity, will have a role in heating and cooling. For areas that require it, synthetic oil and gas produced from coal, shale, or biomass will be utilized. In densely populated areas, waste heat from power plants could be effectively used to heat buildings. It appears that we need to move oil and gas out of the electric sector to uses for which no substitutes can be found. Other resources more appropriate for generating electricity should be implemented, e.g., coal, nuclear, solar, and geothermal. We also list the preferred resources for transportation and industrial use. It is relatively easy for industry to make substitutions for oil and gas, and over the long run they will likely fill in with coal, solar energy, and other resources. We can use coal and, in some cases, wood as feedstocks to produce the chemicals and petrochemicals that we need. And, finally, in ground transportation we can use electricity and/or synthetic liquids. In aircraft we need to use synthetic liquids produced from coal or shale. The emphasis then is on restricting oil and gas to those uses for which we have no other alternatives and on using the resources that are abundant in the appropriate way for electric generation and for industrial needs.

INTERNATIONAL CONTEXT

I'd like to turn now to the international picture. In Figure 8 we have a plot that is used quite frequently to show the value of energy in producing wealth or GNP in various countries. The points without the circles drawn around them represent the per capita energy usage and per capita GNP for various countries in the world. You see that there is a definite trend line, representing an average energy GNP ratio. The countries below that trend line are generally the countries that are resource poor and that must import most of their resources. They have seen higher energy prices for a long time and have accommodated to them by more efficient use of energy in their economies. They have the kinds of societies and life-styles that make very effective use of energy. On the other side of that trend line, you see countries that are rich in resources. These countries have not had to

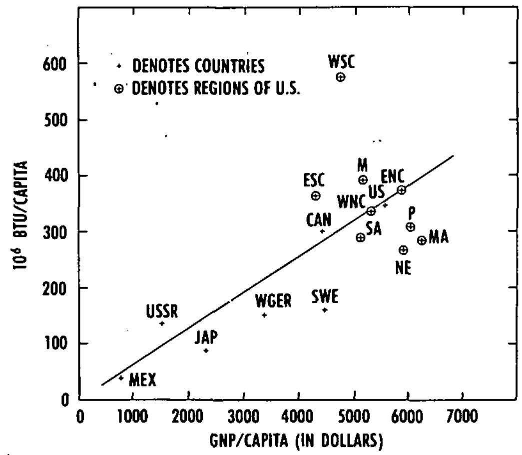

Figure 8. Relationship between per capita energy and GNP, 1972.

conserve energy to the extent that the others have and, consequently, they use more energy in producing their national wealth. The U.S., you see, is at the upper right hand of the diagram with approximately an average energy GNP ratio. For policy purposes we often make comparisons with Sweden, since their standard of living has increased quite significantly since 1972 and is close to ours. We often ask: Why can't the U.S. be like Sweden in the efficient use of energy? Well, first, the U.S. is a big country and is quite spread out. We do a lot of traveling between dispersed urban areas. It is really more meaningful to look at various regions of the U.S. and compare them with some of the other countries in the world. That is what the circles indicate on the diagram in Figure 8 – the per capita energy use in GNP income for various regions of the U.S. For example, the circled point labeled NE is the Northeast and so on through all the census regions. You see that the Northeast is well below the trend line – on a line that would pass through Sweden if drawn back to the origin. So, in the Northeast, circumstances are similar in some ways to those of Sweden; we import most of our fuels, we have more densely populated regions, we have a lot of multifamily homes, we have a good bit of mass transport (although we don't use it to the extent that Sweden does), and we do not have the heavy industries such as iron, steel, petrochemicals. We have some of those industries in New Jersey but certainly not as many as in the South Central states. When you come to the West South Central states (WSC) at the top of the curve, we find that energy is used very intensively because of the energy-intensive industries located in that region. So, for energy policy analysis, we really must consider these regional differences within the United States. It becomes more meaningful to compare regions of the United States with other countries and to look for appropriate technologies and policies that might be transferred to the United States. The point of this figure is to indicate that this comparison must be done on a regional basis. When we do this, we find that we are not doing as poorly as some would suggest.

Figure 9 shows the same information on per capita energy use plotted a little differently. You will note that the United States, on a per capita basis, uses about six times as much energy as the world average. You also see, as you go through some of the developed countries and then on down to the developing and less developed countries, that there is a tremendous variation in per capita energy use. Now, one approach to this problem is to make it a long-term altruistic goal to raise the entire world to our level of per capita energy consumption and provide everyone with all the goods and services that we now enjoy. Indeed, a lot of analysis of that kind was done, and it was demonstrated that it was feasible. Such a strategy

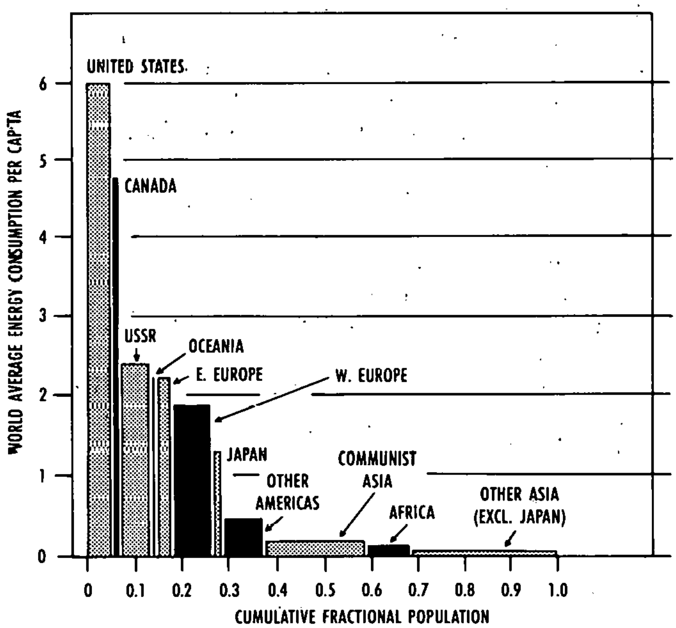

Figure 9. Distribution of per capita world energy consumption.

would require large-scale use of nuclear power throughout the world. That was the view ten or fifteen years ago.

We now regard this goal as very difficult to achieve, given proliferation problems and other environmental concerns. I think that this causes a tremendous change in the role of the United States in the world and in the perception that other countries have of our way of life. There was a time when the United States was viewed as the wave of the future. Other countries could look at the way we lived and aspire to achieve that themselves; our way of life was quite popular. If we now turn around and say that we really do not like the kind of technology required to lift the rest of the world up to our level of consumption but that we are going to continue to live the way we do, consuming these vast amounts of resources, their perception is going to change tremendously from one of viewing us as the wave of the future to that of viewing us as robbing them of their future. That change in perceptions could be a cause of tremendous international tension. That is quite a dilemma and one that challenges us. Clearly our policies must emphasize conservation and a more equitable distribution of wealth around the world.

POLICY ISSUES

Let me proceed now to some policy issues. Our policy discussion must start with imports. What degree of self-sufficiency are we going to try to achieve? There is a school of thought that says we should continue to import as much energy as we can get, that it is better to use other people's fuel and resources and conserve our own than to run out of ours first and have to go into the world market for these resources. We must finance these imports and the problem becomes one of *balance of payment in trade.* Now, when we pay the producing countries for these imports, they have to reinvest these revenues somewhere, and it does appear that most of the revenues are coming back into the U.S. The producers are worried about investing in those countries that appear to be unstable politically. Thus, we are getting the oil, and we are also hoping to get a lot of the money flowing back, or recycling, into our economy. We do have to be careful though. There is the other political problem that some of those countries that may not receive recycled oil revenues are our friends and allies. We have to make sure that they remain stable with sound economies. Foreign policy questions arise here. We've got to have a program of international aid and assistance that makes sure that our friends and allies do not go under as a result of this world trade in oil and the amount of money that is moving into the hands of the producing countries. Other aspects of the balance of payments problem must be dealt with in the broader context of international trade of all goods and commodities.

The next critical element of policy involves pricing. We have had a policy of trying to maintain the price of energy at a low level while still encouraging conservation. In our society it is foolish to expect producers in the U.S. to produce energy at a loss. It is also foolish to expect consumers to save something that is fairly cheap. So it is likely that pricing will be an important part of any policy. Many feel that energy prices must increase to give encouragement both to producers to produce energy and to consumers to conserve it.

Technology, along with research and development, is a very important policy area, but it is frequently ignored or overlooked because of the long-term nature of that research and development. You cannot begin R&D on a new technology and expect to move that new technology into the market place the next year or even within 5 or 10 years, if it is a sophisticated process or activity that you are trying to develop. With such projects, there is not a near-term payoff. There is, therefore, always the danger that, when there is a choice between R&D and other policy actions with a short-term payoff, R&D will be set aside. But if you look at history and the great trend of improvement in labor productivity and energy productivity, as illustrated in the first few figures, you will note that this improvement is the result almost entirely of the development of new technologies. Over the long term, technology is absolutely critical to the resolution of our problems. Clearly, we must give due attention to long-run solutions and to the role of new technology.

There are other important policy issues dealing with decentralization of the energy system. Some people feel we have gone too far toward central station power plants. If we have energy-producing activities far removed in a geographic sense from the benefits of using that energy, then we have a population unable to see the appropriate trade off of environmental concerns for the benefits they get from consumption. Much of that particular problem would be solved if we had a decentralized energy system, where each region had its own local energy system, or generating plant. Then the effects of producing energy could be directly related to the service obtained from it. That would, of course, lead to a different attitude towards the siting of energy facilities.

The degree of decentralization appropriate to our energy system is closely related to population density. In rural areas, decentralized systems of 10 to 20 kW might be appropriate, while in suburban areas energy facilities on a community scale of 5 to 10 MW might compete effectively with large centralized utilities. In an urban area, generating plants of 250 MW size, sited near the population, would allow the use of waste or by-product heat for space conditioning. Thus, it appears that the appropriate degree of centralization or decentralization must be analyzed as a function of population density.

The degree of electrification of the energy system is also a controversial policy issue. Many feel that the losses (about two-thirds of the energy input) associated with the production of electricity are intolerable. Indeed, there are energy flow charts that show these losses quite graphically. Such oversimplified analyses ignore the fact that electricity is a high-quality energy form that can

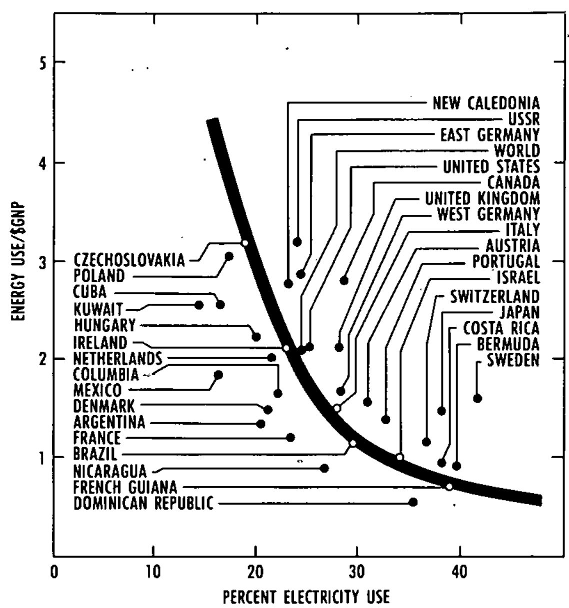

Figure 10. Greater use of electricity boosts energy efficiency.

provide energy services including heating (by heat pump) and transportation much more efficiently than alternative fuels. This is easily illustrated by means of the Reference Energy System, shown in Figure 4, that deals with the entire energy system including the characteristics of the end-use device. There is also evidence that increased electrification leads to the more efficient use of energy in the overall economy. Figure 10 indicates that those countries with a higher degree of electrification use energy more efficiently in producing a dollar's worth of GNP, or goods and services.

Fuel switching is vitally important in matching resources to specific end uses as indicated in Table 2. Such switching may be encouraged by giving stable long-term price signals to consumers and producers to serve as a proper basis for their decisions.

CONCLUSION

I would like to conclude by saying that most of the issues that I have addressed here should be considered in a balanced way in the formulation of an energy policy. I definitely do want to leave you with an impression of uncertainty about the future and the trade offs that have to be made, and the need for a flexible and adaptive energy policy. The last thing we would want to lock ourselves into is a policy that cannot be modified when situations change or when more information is forthcoming. We need to maintain a flexibility. The good news that I would like to leave with you is that, on the basis of our analysis and other analyses, there appears to be a feasible path through the future, through the transition problems I have outlined, that will allow us to attain the kind of lifestyle and equitable structure of society that we think is appropriate. On the other hand, we must be aware that this process is going to be very difficult. You have heard of some of the international problems that lie ahead with respect to the world economy and our role as the model of future society. We clearly need very close coordination of our domestic economic policy and our foreign policy with the energy policies that we formulate. Finally we will have to sacrifice, particularly to protect those in our own country who will suffer most from energy problems, the lower income groups. We must also sacrifice to protect other nations of the world – the less developed countries and the developing countries that will go through a very difficult period if the kind of problems we have seen persist. There must be a national and an international effort to try to resolve these foreseeable problems.