Resources and Economic Growth

The future costs and availability of oil and other minerals essential to the American economy have not loomed large as issues in the 1976 Presidential campaign. The "energy crisis" of 1973–74 has faded from public attention, leaving a legacy of higher fuel prices, a national 55 m.p.h. speed limit, and a lingering uneasiness, perhaps, about the long-term exhaustion of the earth's finite resources. Forecasts by the specialists vary widely. There are optimists like Geologist James Boyd who see technological solutions; pessimists like Systems Analyst Dennis Meadows, co-author of *The Limits to Growth;* and those in between like Nuclear Physicist Alvin Weinberg. In a lively "evening dialogue" earlier this year at the Wilson Center, these three men and their audience examined major issues that crop up in discussions of resources and the future. We present an abbreviated transcript of their debate, then excerpts from essays by Walt W. Rostow, Henry C. Wallich, and Eugene B. Skolnikoff on the long-range outlook.

THE AMERICAN FUTURE: A DIALOGUE

JAMES BOYD: That the question of the future availability of mineral resources has to be asked at all reflects basic misconceptions in what is currently the conventional wisdom.

The question arises, first, from a failure to comprehend the magnitude of resources available to human development; second, from a general lack of knowledge of how we use resources; and third, from a few isolated failures to provide certain minerals when and where they are needed.

Geologist James Boyd, 71, is president of Materials Associates. Born in Kanowna, Australia, he graduated from the California Institute of Technology (1927) and the Colorado School of Mines (1934), and taught until World War II. He served in various Army capacities, then ran the U.S. Bureau of Mines in 1947–51. A former Kennecott Copper executive, he directed the National Commission on Materials Policy (1971–73).

Physicist Alvin M. Weinberg, 61, is director of the high-level Institute for Energy Analysis at Oak Ridge, Tenn. Born in Chicago, he received his B.S., M.S., and Ph.D. (1939) in physics from the University of Chicago. He served with a wartime team of U.S. nuclear physicists, then moved to the Atomic Energy Commission's big Oak Ridge National Laboratory, which he directed from 1955 to 1973. He helped design the first nuclear power reactors, became a writer and lecturer on science policy, served in the Federal Energy Administration (1974) and on numerous national advisory panels.

Systems Analyst Dennis L. Meadows, 34, is director of the Research Program on Technology and Public Policy at Dartmouth College. Born in Tulsa, Okla., he earned a chemistry degree at Carleton College (1964), and a Ph.D. in management at MIT (1969), where he taught until 1972. For the Club of Rome, he helped produce three books, The Limits to Growth *(1972),* Toward a Global Equilibrium *(1973) and* Dynamics of Growth in a Finite World *(1974). Like Weinberg, he was a Guest Scholar at the Wilson Center in 1973.*

It is our concentration on the size of known reserves of raw materials in relation to the rate of their consumption that has led us to believe that our resources will be exhausted within a relatively short period of time. This confusion of economic and geologic measurements has blurred our view of the real situation, and is more likely to impede material growth than is the state of the natural resources themselves.

Therefore, I think it is important that we lay the foundations for discussion on a sounder premise.

The first principle is that all materials are used for the properties they display. We do not use copper because it is copper, but because it has the properties of electrical and heat conductivity, corrosion resistance, malleableness, and appearance. We do not use natural petroleum because it is oil, but because it provides energy.

The exhaustion of natural petroleum resources does not mean that our needs cannot be met by energy obtained from more abundant sources. I know of no function of current industrial society that cannot be performed by more than one material.

There are functions that cannot be performed as efficiently with interchanged materials as they might be, because the right material or process has not yet been discovered. But as technology changes, the operating number of interchangeable materials increases.

Recent developments in technology have already made important strides in this direction. Processes that did not exist a few years ago except in the most imaginative minds now make the use of certain "new" materials very practical.

The ability to interchange materials gives a new order of magnitude to the estimated size of resources available to us in the earth's crust.

Although the accessible parts of the earth's crust and oceans are only a small part of the total mass of the earth, they are enormously large. The United States Geological Survey and the Battelle Memorial Institute have calculated that within a kilometer of the surface of the earth (within reach of modern extractive technology) there are about 400 trillion metric tons of usable materials.

The entire world consumption of sand, gravel, oil, coal, and metals is only on the order of 22 billion tons a year. At this rate, we should be able to support ourselves for at least 20,000 years—enough time, it would seem, to adjust our institutions and population growth to the resources that are available. . . .

ALVIN M. WEINBERG: Two conflicting views dominate current perceptions of man's long-term future.

The "catastrophists" believe that the earth's resources will soon be exhausted, and that this will lead to a collapse of society. The "cornucopians" argue that most of the *essential* raw materials are infinite; that as society exhausts one raw material, it will turn to lower grade, inexhaustible substitutes; that eventually society will subsist on renewable resources, and on those elements that are practically infinite, such as iron and aluminum. According to this view, we will ultimately settle into a steady state of substitution and recycling.

It seems to me that there is a convenient way to place these views in perspective.

About 80 percent of all the molecules we take out of the earth and use is *fossil fuel.*

How much of this fuel is there in the earth's crust? There are about 25 parts per million. We have here an extraordinary situation: man's whole technological civilization is based on an addiction to a material [fossil fuel], an addiction that really can't be broken.

There is more of this fossil-fuel material in the earth's crust, but most of it is so finely dispersed that it would take more energy to extract it than we would get by burning it. That is the energy crisis in a very oversimplified nutshell.

The fossil fuels present a unique problem of scarcity as far as our mineral supply is concerned. But if we turn to the next material that man uses—the metals—we find a very different situation.

We find that 86 percent of all the metal atoms that the United States uses is iron. The next most common is aluminum, which makes up 8 percent of all the metal atoms used. Aluminum is the most abundant material metal in the earth's crust. Now when one speaks of digging out the first kilometer of the earth's crust, one isn't sifting through to find something that's very difficult to find.

Well, what about copper? My calculations are that, if our rate of consumption of this material continues at less than three times the current rate, we have millions and millions of years worth of available copper, essentially everywhere.

What about mercury? Mercury is by no means an abundant material, and the United States alone consumes about 2,000 tons of it a year. Judging from its crustal abundance, the price of mercury will undoubtedly rise very high. The issue, then, is: How essential is mercury to the pursuit of happiness and to the conduct of our technological civilization?

Of the 2,000 tons of mercury used by the United States in 1968, the largest fraction went for the production of caustic and chlorine. Do we have to use mercury for this purpose? The answer is no.

The diaphragm cell is an alternative that was in wide use before the mercury cell was introduced, and still accounts for 70 percent of the U.S. production of caustic and chlorine. This cell requires relatively common materials—concrete for the cell body, asbestos for diaphragm, and copper and graphite for electrodes.

The conclusion that can be drawn from these illustrations is that, as far as mineral resources are concerned, this society is primarily based on materials that are present in very large quantities and at high concentrations. For those elements that are not present in high concentration, there are, on the whole, large possibilities for substitution.

It seems very evident that any estimate of the long-term future of the world must depend upon the realization of some kind of energy source other than the fossil fuels.

But are there any minerals whose long-term situations seem as touchy as that of the fossil fuels? Phosphorus is one that H. G. Wells pointed out a long time ago in *The Spectacle of Life* [1931]. There is no substitute for phosphorus. And there are other scarce ones: the trace elements that are required for agriculture, possibly beryllium, and silver.

Well, without silver, the quality of photography will almost certainly diminish because silver halide constitutes the light-sensitive emulsion on most film. As far as the quality of life is concerned, however, I think that of those I have mentioned, phosphorus and the trace elements are the only ones we really need to worry about.

I view the present stage of the world, in which we're using up the fossil fuels at such a terrible rate, as Stage I. I see Stage III as the Age of Substitutability—the age visualized by Jim Boyd when he speaks of the development of functional mineral substitutes.

The real problem, as I see it, is how we go from Stage I to Stage III without foundering.

It has often been argued that the market system will be sufficient to carry us over. I'm not sure.

The market system is obviously failing to produce the needed transition in the case of fossil fuels. Yet I don't think it will be quite so inefficient in the transition from bauxite to clay as our main source of aluminum because the difference in price between these two will be much less.

I think we have to be careful not to confuse the specific bad situation represented by energy with other situations where the means of substitution are broader and offer more grounds for optimism.

DENNIS L. MEADOWS: My goal this evening is simply to describe a point of view sufficiently distant from Alvin Weinberg's so that there will be some room for debate. Time pressures will force me to be a bit more dogmatic and extreme than is my custom.

I believe that, over the next 30 or 50 years, mineral-resources scarcity will influence Western economic and political institutions toward drastic reductions in material growth rates and in the options open to our society.

Problems will arise, not because we will have exhausted the last atom of useful material from beneath the surface of the earth, but because the irrational institutions, the short-sighted political goals, and the illogical geographical boundaries which the "cornucopians" view as temporary irrationalities are likely to persist for many decades.

Resource availability is not a question of whether there are molecules of a specific element beneath the surface of the earth. Resources are available, in a pragmatic sense, only when those molecules that do exist can be located, extracted, refined, distributed, and manufactured into a diverse set of useful products—at a cost that society can afford.

Moreover, resource availability involves questions of equity. The provision of adequate resources for 10 or 20 percent of the global population is not going to be sufficient. And as we look at the political, economic, technical, and geological factors that produce resources, we see an *intensification* of several *institutional attributes* that are likely to cause a great deal of trouble.

The first reason for concern about our ability to ensure a steady flow of natural resources is the extremely long delays involved in the process of technological change and resource substitution. The shift from wood to coal as the dominant U.S. energy source required 60 years. The shift from coal to oil and gas required a similar period. There is no reason to believe that the move from oil and gas to other sources of energy will be any faster.

Indeed, rising environmental concern and the scarcity of capital are likely to slow down the adaptive process. It may require 20 years or more to establish the technical feasibility of a new [nuclear power] technology like fusion.*

A decade more may elapse before proven scientific principles are demonstrated in a technology that is commercially attractive.

Then several decades more may elapse before society has been able to amass the capital required to employ the technology on a wide scale. Even if the capital and technical knowledge were available in infinite supply, decades of slow accommodation and change would be required to effect the shifts in employment opportunities and economic power implied by a substantial change from one resource technology to another.

*Unlike the process of nuclear fission, which involves the splitting of atomic nuclei (the heavy isotopes of uranium or plutonium), nuclear fusion combines naturally repellent nuclei (generally, heavy hydrogen isotopes extracted from water) to form heavier nuclei (i.e., helium), thus releasing enormous quantities of energy. Still in the highly experimental stage as a source of power, the fusion process is thought to offer these advantages: high efficiency, abundant fuel, greater safety, little radioactive waste, and no thermal pollution.

Yet delays would not in themselves produce the negative results I project if they were not coupled to the short "time horizon" of most government agencies and corporations responsible for resource policy.

Decision-making in corporations is conditioned by interest rates which encourage a gross indifference to costs and benefits not realized within five years.

With political institutions, the spectre of the next election prevents the implementation of any policy that may return great benefits over the long term but that also forces costs on important interest groups over the short term. The fact of Congress legislating a *reduced price* for petroleum at the instant when all agree that raised prices are required to spur exploration, promote conservation, stimulate development of alternate energy sources, and reduce imports can only be understood as an effort to gain favor with the electorate.

Even bureaucrats not subject to election have a short time perspective. An Assistant Secretary of the Interior once pointed out that the average term in office of someone at his rank is about 21 months. The first 6 months are spent trying to figure out what's going on, the next 9 months are spent doing something, and the last 6 months are spent trying to figure out where the next job will be. So there is very little incentive to sit down and develop long-term programs.

When you couple the long delays we require with the inescapably short time horizon of almost everybody who is making the decisions, when you recognize that those policies which produce desirable long-term results typically are relatively painful in the short term, you see that we're locked into a dilemma—a dilemma that virtually guarantees more resource problems like the energy crisis. The dilemma is ignored by many because we have developed a set of myths about resources and resource availability that sustain our confidence in the ultimate efficacy of short-term policies.

The first is the myth of the top mile of the earth's crust. There is an enormous amount of various mineral elements in the top mile of the earth's crust. But there is also an enormous amount of crust. As soon as one has to start sifting through the crust and disposing of it in some way that does not interfere with other important economic or biological functions, the capital costs become so high that most materials in the crust are not available to us.

Oil shale provides a very nice illustration. There is an enormous amount of oil shale in the top two or three hundred feet of the earth's crust. But the problem of shale waste disposal may block that resource from ever being available.

Another myth is that of the "need for regional interdependence." To assume that interdependence benefits everyone is to treat reality in terms of rather narrow economic criteria. In fact, what governs the international flows of oil, metals, and other resources has much more to do with personal ego, institutional power, conflict, and the relationships among different nations than with economic factors. It is that political reality, not the economic one, that is likely to govern many of the resource flows in the future.

Third, there is the myth about the price system. It is asserted that price change will always call forth new substitutes and new practices that will permit us to shift quickly and smoothly from one resource to another without any decline in our options, or perhaps even in our material standard of living. But as I have pointed out, the determinants of the price system are geared to the *short-term* consequences of an action. Thus, price changes simply provide no signal about the *long-term* forces at work in determining resource availability.

The energy system again provides an excellent example. During the 1950s, this country should have begun the development of new technologies and the design of new institutions that could provide energy after oil and gas are depleted. However, during that period, the economic system produced a declining price for exactly those [oil] resources that were most rapidly diminishing.

It has been argued that declining energy prices in the 1950s were an anomaly produced by interference in the "normal" market system by Congress and the Federal Power Commission. However, I believe such anomalies are, in fact, the standard outcome. There will always be interference in price and production by shortsighted interest groups as a resource approaches depletion. The pure price system is likely to disappear for any resource just at the point where economists have led us to believe it would call forth the economies, substitutes, and technological advances required for adaptation to scarcity.

The final myth is reflected in the method typically used to determine how much of some substitute material will become economically available at a small rise in cost. Most calculations have assumed that substitutes could be *sold* at future, and higher, prices, but produced at current price levels.

The fallacy is illustrated by a set of calculations that were performed to assess the substitutability of oil shale liquids for conventional oil. When oil was selling for around $3 a barrel, the Atlantic Richfield staff calculated that they could make a profit from oil shale liquids if they could be sold for $5 per barrel. However, once oil went to $5 per barrel, the same forces that had brought it to that level also affected the costs of labor, capital, and energy. As a result, the break-even point for oil shale calculated by ARCO rose to $10 per barrel. Of course, oil now sells for that price, but the break-even price for oil shale is now expected to be up around $20 per barrel.

The myth has been to assume that resource prices rise in isolation from other inputs in the economy. In fact, resource depletion sets in motion a broad set of economic and social forces producing price rises in many parts of the economy.

The above notwithstanding, I do not believe it is physically necessary for the limited physical endowment of this earth to intrude on our development. The materials that are available easily could, in some utopian system free of institutional and political constraints, provide us with a full spectrum of clothing, jobs, transportation, shelter, and recreational opportunities. But until we can figure out some way to attain that utopia, I think we are well advised to be very concerned about the impact of resource scarcity on our progress in attaining social and economic goals.

JAMES H. BILLINGTON, *moderator, Director of the Woodrow Wilson International Center for Scholars:* It seems to me there are two interconnected questions raised by what has been said: How specific is the problem of energy? And how can we in fact manage the change from Stage I to Stage III, the Age of Substitutability?

MEADOWS: I don't find myself being very reassured by the statement that energy is a special case. I think that the forces which are giving us so much difficulty in the energy system are latent in the other industries as well.

I strongly agree with the notion that we study each individual material and see what kind of problems it poses. But I think it is probably true of iron, aluminum, copper, etc.—as it is true of energy—that as we turn towards more distant, more diffuse deposits or as we are forced to use deposits that, in the process of extraction, produce undesirable environmental consequences, the energy cost and the capital costs of securing them will increase.

WEINBERG: Well, the essential message that I have been trying to put across is that, for 95 percent of the metals that man uses, these cost increases *will not be large.*

How much is a large increase? I don't know. I suppose, from a cosmic point of view, multiplying the cost of extracting a mineral by a factor of two is not a large increase. However, I will concede that if that factor were applied in a hurry, then it would be a large increase.

BILLINGTON: I haven't heard any ringing sounds of endorsement, yet, for the free-market system as the means of taking us to Stage III. What alternatives would you propose? The Soviet Union, with its centrally planned system, seems to have considerable difficulty with the kind of materials substitution you describe. If you say the only question is how we get from here to there, what are your models?

MEADOWS: Well, I don't know the answer to that question. But I've spent a good deal of time thinking about it and, although I can't give a precise recipe, I think I know some ingredients of recipes that are more likely to be successful.

The first ingredient clearly involves a deliberate, societal shift toward placing an intrinsic value on conservation and zero material energy growth—*deliberate* because, although this shift may in fact be mandated by economic factors, the signals that the economic system will provide as impetus will always come too late to avoid serious problems.

WEINBERG: I think that in many instances the market system will work better than you think. Right now, for instance, there is talk of mining clay instead of bauxite in Alabama to get aluminum.

What worries me is whether the free-market system will work in the case of energy as well.

CLARENCE D. LONG, *U.S. Representative (D., Maryland):* I don't see that energy is any different from the metals. There are all kinds of sources of energy. There is petroleum, there is coal, there is the sun, there is nuclear energy, geothermal energy, and there are possibilities of hydrogen energy [nuclear fusion], at least in theory, that are almost breathtaking. All of these are substitutes, depending on the costs.

How can we talk about the exhaustibility of energy? I don't think we can talk very much about the future because I'm sure that within the next 10 or 20 years new energy sources will be developed that may make our discussion here seem a little naive.

MEADOWS: I would like to correct an impression that is sometimes engendered by the use of the word "inexhaustible." There are certain fuels—geothermal heat and higher molecular weights of hydrogen [used in nuclear fusion], for example—that can provide an infinite amount of energy, in the sense that we can never exhaust them. But this doesn't mean that we will ever have an infinite amount of energy. In fact, I suspect that we will never again have as much energy as we've had over the last couple of decades.

WEINBERG: Are you saying that society, 10 years from now, won't be using more energy than we are using today?

MEADOWS: I'm saying that the United States will be forced to accept a per-capita energy consumption level *lower* than it has today, even if it begins to make use of "inexhaustible" sources of energy. These sources may be inexhaustible, but there are very serious rate constraints associated with their environmental impact, the amount of heat they release, and their requirements for exhaustible materials such as metal and land.

We have no reason to believe that these "ultimate" sources of energy will give us an infinite amount of electric power. Nor do we have any cause to expect that the capital costs will be as low as our power costs have been over the last couple of decades; they may be much higher.

Yet I hope we begin to use these ultimate sources of energy. I think they're our only hope.

LONG: Aren't we perhaps fortunate to have a limit to economic growth in the form of available energy? Suppose we had an absolute abundance of energy to the extent that energy became almost a free good. I doubt very much whether our problems would be solved.

One of these problems, of course, is pollution. The Japanese are living in conditions now that may suggest our own future condition. I understand that they have 50 times the concentration of population that we have, and that they are basically living in filth.

I think we have to consider the problem of heat. I read somewhere that if we ever have all the energy we want, we might heat up the atmosphere, melt the polar ice caps, and flood most of our coastal cities. I don't know whether that is a joke or a real possibility, but more intelligent people than I mention it as a consideration.

I think other problems may arise in the form of the social strains that seem to accompany unlimited growth. When you live in a little house in the woods, you can fight with your wife, you can play the radio all night, you can hold wild parties, and nobody complains. But when you live in an apartment house, there have to be rules: no radio-playing after 11 o'clock, no wild parties, no pets. The complications of life increase enormously as the population becomes more concentrated.

If we eliminated every restraint to economic growth, I think we would get a population growth that would surprise even Malthus. And I think it would mean the end of democratic society as we know it.

MEADOWS: I think that's a fairly important remark.

Implicit in the question, "Will mineral shortages impede growth?" there seems to be the assumption, "to stop growth is bad." But thus far we've discussed only material growth—growth in the massive consumption of materials and energy.

I think we should devote some of our intellectual resources to the question of whether material growth shouldn't indeed be stopped, recognizing that this might not immediately be an appropriate choice for all of mankind, but that it might be a very appropriate choice here in this country.

Instead of blindly lashing out to try to sustain growth on all fronts as our mineral resources approach depletion, we should consider the possibility that we are now being presented with an option: Do we continue to measure growth simply by Btu [British thermal unit]? Or do we direct ourselves along a path where growth as a social dimension is the goal?

ETIENNE VAN DE WALLE, *Professor of Demography, University of Pennsylvania, and Wilson Center Fellow:* My studies have centered on the demographic changes that occurred in Europe during the nineteenth century, so I must disclaim any special insight into the future. Yet, as we attempt to predict the future of the high fertility rate that prevails in much of the world today, a knowledge of the past may help us.

During a remarkably short span of time—between 1880 and 1900, in most of Europe—there occurred a rapid and pervasive social change, as country after country abandoned its high rate of marital fertility and adopted contraception on a wide scale.

I am optimistic that the same change will take place in the rest of the world. Fertility rates are decreasing even now; and if the Western experience of the nineteenth century tells us anything, it is that this trend is contagious, irreversible, and rapid once it has started. Fertility rates are now on the decline in much of Asia—including China—and in parts of Latin America. And the fertility rate in the West is lower than it has ever been. (It won't be long, I think, before the alarmists cry that we are moving toward extinction.)

Although an end to the population explosion is likely only in the long run, and the population of the world will greatly expand before the momentum of that explosion is spent, the steady improvement of contraceptive technology and a spreading awareness of the financial advantages of the small family are bound to triumph in time.

BOYD: I'm delighted that there is another optimist here.

We don't have to solve our energy problems all at once. Bit by bit we can build a new energy system. Granted, we don't have the technology to gather solar energy and distribute it by power lines. But every household in the United States could be heating its water by solar energy.

We have got to challenge ourselves to solve our problems.

CHESTER L. COOPER, *Director, Washington Office of the Institute for Energy Analysis:* Gentlemen, the question is no longer whether mineral shortages will impede growth. We've answered that. They won't. The question is will *institutional problems* impede growth?

Mr. Boyd suggests that there are constraints because of social problems. Dennis Meadows surprises me a bit because I think he has shifted his focus, at least as I remember it, from physical limits to growth to institutional limits to growth. Yet he hasn't really answered the question. Alvin Weinberg, by fudging a little on his Stage II, hasn't really given us much nourishment, either. Where do we go from here? Are we studying the wrong questions?

WEINBERG: Chet, you know as well as I do that none of us can answer the hard questions. So we talk about the easy ones.

Is the market system adequate to deal with the transitions from one kind of material to another?

It has been notably successful in shifting from magna type iron ore to taconite. When magna types were being used at the Mesabi range [in Minnesota], people had no idea that the shift to taconite would be relatively easy.

On the other hand, when substitutions are very capital intensive and involve very large shifts, such as the transition from Saudi Arabian or Alaskan oil to shale or synthetic oil, there seem to be enormous institutional problems.

Yet I don't think we will have answers to your question except through further study. One study that I think ought to be undertaken is an examination of those instances where the market system has been successful in allowing mineral substitutions and those instances where it has not.

MEADOWS: I'd like to get back to the problem of injecting a long-term perspective into our current institutions.

We have to have a goal. Perhaps we should redirect some of the energy that is being poured into our Bicentennial celebration toward an examination of where the hell we're going in the next 100 years. There should be a plan, there should be many plans, debates about plans.

We need institutions, vested with a responsibility for the future, that can start thinking about these questions and that can present ideas without political interference on the part of short-term thinkers. The Office of Technology Assessment in the Congress was established [in 1972] to investigate the social consequences of various technologies. And there is now under consideration a "Policy Institute" for Congress that would cut across committee boundaries and be responsible for contributing a long-term perspective on committee legislation. These are some examples.

There is a lot of methodological work to be done. We will never be able to predict the future, but we can certainly develop techniques for organizing information in an objective way that will enable us to rule out certain outcomes and focus our attention on those that are desirable and feasible.

WEINBERG: Yet it seems to me that the energy problem has preoccupied us with the future in a way that is too explicit and terribly constricting.

I was with Federal Energy Administration at the time of the [1973–74] oil crisis, when President Nixon set the goal of "energy independence by 1980." He was told that that was impossible; so it was then changed to "energy independence by 1985." We could argue whether or not *that* was a good goal, but it was the goal, nevertheless.

The Federal Energy Administration then took up the task of attempting to foresee the future to 1985. We set up a computer model which cost millions and millions of dollars and, so help me, we came out with projections of what the future to 1985 would be. These were incorporated into the Project Independence report.

There was only one difficulty: the entire exercise depended upon the selection of *one* number which would represent *elasticity of demand*. That number was entered as −.756.*

Well, the conclusion was drawn that energy demand is very sensitive to price; and the administration policy since that time has been to assume that if prices are raised, the energy problem goes away. It seems obvious to me that that policy stems from the use of −.756 as the energy demand coefficient.

Now the whole exercise is being done over again. This time it's been decided that −.756 was too large and that maybe the number should be −.4 [meaning that gasoline demand is only about half as sensitive to price increases as the FEA originally thought].

I think this example shows that we can depend too much upon this kind of explicit modeling for seeing the future. We are not endowed with the capacity to foresee the future. We are expecting more from our techniques than we can get.

JAIME BENITEZ, *Resident Commissioner from Puerto Rico:* It seems to me that the obstacles to attainment of Stage III are more emotional and cultural than intellectual and rational.

Twenty years ago, Dr. Weinberg came to Puerto Rico to develop a program of nuclear sciences at the University of Puerto Rico that would help prepare the overcrowded island to deal with its enormous energy problem. Yet, to a large extent, Puerto Rico has been unable to implement the science of nuclear energy because of a strong emotional reaction to

*Elasticity of demand is a concept used to show how changes in price affect the amount of demand. This is expressed through what is called a coefficient of elasticity. It is calculated as follows:

$$\text{Demand elasticity} = \frac{\text{Percentage change in quantity of demand}}{\text{Percentage change in price}}$$

When the result is expressed as a negative (−), this means that the demand has decreased and the price has increased. If a coefficient of −.756 is used, as was the case with the FEA, this means that reduction of demand follows closely when price increases.

what happened more than 30 years ago at Nagasaki and Hiroshima.

I think it is fair to say that there is a real hostility to the development of nuclear energy—a hostility that is to a large degree irrational, but that is also an expression of environmental concern.

I would like to ask Dr. Weinberg if he thinks we will ever be able to realize a nuclear energy *system*, given this emotional hostility.

JOHN F. SEIBERLING, *U.S. Representative (D., Ohio):* I am one of those people who have that "irrational" attitude toward nuclear energy—only I prefer to describe it as a realistic concern. Given the possibilities of nuclear sabotage, the hijacking of nuclear materials, and, within a decade or so, the manufacture of plutonium bombs by politically primitive countries, is the world ready for the nuclear energy system that you, Dr. Weinberg, and others seem to think is necessary to meet our problems? The question bothers me, and it bothers many other members of Congress, too.

WEINBERG: Will the anxiety over nuclear energy deny the nuclear option to us? Possibly.

Do I think this a proper course? My answer is a very strong no, because if we look at the options that are available to us, we find that there is risk in all of them.

MIHAILO MARKOVIC, *Member of the Serbian Academy of Sciences, Belgrade, and Wilson Center Fellow:* Do you think fusion is going to work?

WEINBERG: Well, I've been in the fusion business for about 30 years—ever since it began. During tests, some of my colleagues have said to me, "We're going to get fusion. It's going to work." And my response has been, "Okay, I'll bet you a dollar it won't." I collected on that bet in 1957, and again in 1959, and I've collected ever since.

I guess my basic feeling is that the problem of developing a fusion system is so immensely difficult, that if I were asked whether fusion will work in my lifetime, I would be prepared to bet half my fortune that it won't. If I were asked whether it will ever work—well, ever is a long time, but it just looks very difficult to me. . . .