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"Energy Resources"

Harrison Scott Brown

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HOST [in background, muffled]: The topic is something that Dr. Harrison Brown has been involved in for many years: energy improvement. Instead of having these topics separated, […] he feels they ought to be integrated […] So, there are two lectures, really, […] in order to get the full picture of the relationship […] resources […] in one neat, complete package. Those of you that may not know Dr. Brown and would like to visit with him some time during the break or maybe to find out more about him personally; he has recently become director of the Resources Institute of the East West Center associated with the University of Hawaii, and the book that he has worked on is a sequel in a sense, a sequel to his previous book, *The Human Future Revisited.* We'll have a copy going around where you can glance at it; this is the only copy he was carrying with him as it's just been released. Some of the ideas will be in this text. Now… I present to you Dr. Brown.

[applause]

DR. HARRISON SCOTT BROWN: Thank you very much. I am going to talk today about a series of global converging forces in which humanity now finds itself, which are converging with rather alarming rapidity. Sufficiently rapidly so that sometime in the course of the next 30 or 40 years, something's got to give. We are headed for a major crunch, and the real major question is, will this crunch come about pretty much all on its own, or can we as thinking, hopefully rational human beings, take the necessary actions which will prevent it?

Now, among these converging forces are such elements as rapid population growth, rapid growth of affluence, the growing gap between the rich and the poor, the East-West confrontation, the growing power and strength of the nuclear umbrella, the spread of sophisticated non-nuclear technology to all parts of the world, the decreasing resource base, the decreasing availability of very inexpensive energy… and I could add quite a few more things, but I think that is enough to keep us busy. My topics involve two of these elements, but I would like to stress that we are living in a highly interdependent world, in which all of these various things that are going on are interlocked with each other and they affect each other. So when we talk about energy, we really can't divorce that from food; we can't divorce any of these things from the increasing power of nationalism; we can't divorce any of these things from poverty in the world, and so forth. So we will be confining our discussion to the most part to energy and food necessity, we must talk about some of these other elements as well.

To fully appreciate the situation mankind is in today, let's look back over the millenia to the kinds of situations mankind has been in before. Originally, human beings, being gregarious, they like to live together; they existed as so-called food gatherers: hunting, fishing, and the like. And under those circumstances, the largest number of people which can live together is determined strictly by the productivity of the land around them and how much of that land they can effectively utilize; how far away can a hunting party go and get meat and bring back before it spoils, and the like. And it turns out that a typical tribe can't be much more than about a hundred people or so. And once food-gathering culture had spread all over the world, the maximum population of human beings that could be supported by, within the framework of that technology, was about five million people, or ten million people worldwide, about the population of the city of New York today. Indeed, when we look at population densities in food-gathering cultures today and those that have been recently become extinct, this seems to be about the worldwide level of population density for the greater part of human existence.

Once that kind of a structure had spread all over the entire surface of the globe, it was very stable. No single tribe was assured, of course, against death. An individual tribe or even groups of tribes could be knocked off by war, they could be knocked off by disease, they could be knocked off by drought over a very large region. But what we call the resilience in the ecological sense was very high, so that once tribes disappeared, then the blank spaces were very quickly filled in again by the powers of population growth coupled with migration. And indeed if you look at the situation, nothing short of a cosmic catastrophe could have eradicated human beings by that time. By that time the human species was in truth the dominant life form on earth.

Now, that situation changed in nature with a tremendous technological breakthrough, namely the invention of agriculture. With the invention of agriculture, it became possible to nurture the plants you can eat, to kill off plants that weren't very useful to you, to kill off competitors from other parts of the animal kingdom competing with you for the food, to… related to agriculture, to nurture animal species that were useful to you, and kill off animal species which were not useful to you. With this new technology, the nomad existence pretty much disappeared; people settled into villages. The maximum number of people who could live in the village was determined by the productivity or fertility of the land around, and by how far an individual farmer is willing to walk out in the field in the morning and work all day and then walk back at night. It turns out this is about 200 or 300 people, and indeed this is about the size of villages in many parts of the world today, in China, in India, and other parts of the developing world. What is India today has about half a million villages in it, which are all sort of loosely connected, but only very loosely connected.

And this is very important. An individual village: its major characteristic is that it is relatively self-sufficient. The people grow the food around, they make their things from the resources in the area, they don't have to import much of anything; there's a little trading that goes on which produces this loose coupling, but for the most part they are self-sufficient. So that kind of a system, again, has a tremendous resilience, and even greater resilience than—because it is so much larger—than what preceded it, namely the food-gathering culture. So that you can knock off a group of a hundred villages through a famine in India or China, and the recovery potential is enormous through the very rapid potential rate of population growth, and through migration. So when holes in this whole matrix appear, they are very quickly filled in again. So although no individual village has any guarantee of stability—they disappear frequently—the system as a whole has a tremendous stability. That is the way that humanity has lived, in which humanity has lived since agriculture spread over the surface of the world sometime during the course of the last ten thousand years or so.

Now, during the course of this, it was found that people on the average could produce somewhat more food than they really needed for themselves and their families. This is very important, because it meant that some people didn't have to be in the business of just producing food for themselves and scrounging around for food, and so they could do other things. And we find associated with this a diversification of tasks, and associated with that we see the emergence of the first cities, composed for the most part of people who didn't have to be engaged in food production; they were artisans of various sorts, soldiers, clerics, artists, teachers. The number of people who could thus be supported by society was never very large, amounting to about 10 percent as a population as a whole. It is important for us to recognize that these people were far more dependent upon the farmers than the farmers were dependent upon them. And indeed throughout the course of history, throughout its flow, we see countless cities that have emerged and disappeared; for the most part they have been buried in their own garbage; then new ones emerge, they disappear. Yes?

[member of the audience asks to raise the volume]

BROWN: OK, I'll try. I don't know if this is connected to a loudspeaker, is it? I can't tell. [voice off microphone in background] So they're hearing me straight, right? OK. I'll try to speak louder. I might not last an hour and a half, but I'll try.

Let me just show a few slides which illustrate… [laughter in background] What? […] Oh. Well… Here we are. Now, can you see that? Here we have a universe of food-gathering tribes. Each little point represents a tribe. There's a catastrophe of some sort, and almost half of them are knocked off, and then you eventually come back with recovery. I'm not getting any… I'm sorry, I was pushing it the wrong way. With the emergence of agriculture and the agricultural transition where many many villages replaced a very few tribes, a very resilient system suffers a catastrophe, many of them are knocked off, and then finally they recover. We find the emergence of urban civilization, an agricultural area, a city emerges within it, there is a catastrophe, the city is knocked off, the agricultural community recovers and eventually another city emerges. A very resilient system that on a worldwide basis is quite stable, except for the cities; the cities are not very stable, although eventually they come back as well.

Could we turn off the machine, please? And that is the way it was until a couple of hundred years ago, with roughly ten percent of the people living in cities and towns, what you would call urbanites, ninety percent of people living on farms, in villages, and with energy, for the most part, coming from what we would call primitive sources, although engineering, the art and science of engineering, had developed to a fantastically high level. For the most part, the task was mobilizing large quantities of energy to achieve pre-conceived goals; these were achieved by the mobilization of gangs of men. The Romans, the Egyptians before them, were able to mobilize literally tens of thousands of men in order to achieve fantastic objectives. Grain was ground by having men push wheels; sometimes animals were used, but it's rather interesting. It's illustrative of how lack of knowledge can prevent social change, but with the harnesses that existed at the time, a horse could only pull four times as much as a man, and at the same time the horse ate four times as much as a man would eat, and a hard-nosed economist at the Roman time, or a hard-nosed businessman would say why use a horse, when I can use a man? He lives longer, and I can teach him to do other things also. So a man turned out to be more economicalm and thus the institution of slavery was perpetuated.

With the emergence of the postilion harness, which came from Mongols across the Asian steppes to Europe, a horse could pull sixteen times as much as a man. So we see, directly associated with the spread of the postilion harness, the disappearance of the institution of slavery as a mechanism of getting heavy jobs done. The water mill came into existence quite early; it spread rather slowly. The Romans used it to some extent, and indeed they built quite a large one right near Naples for the purpose of grinding grain. But the Roman emperors were always very leery of it; they were quite concerned because unemployment was always a problem in the city of Rome. They were quite hesitant to do anything that would upset the status quo, with the result that men were used a great deal in preference to the water wheel. The windmill emerged and spread; it also emerged in the East and spread to the West, and up until about 200 years ago, we see Europe powered primarily by wind and by water; for the most part slavery had disappeared.

And that was the situation that existed when another series of tremendous developments took place which revolutionized human society. This new set of developments had its start basically with the development of steel manufacture, or iron manufacture rather, on a large scale, and its spread. England was richly endowed with iron ore and it was also richly endowed with forests, and at that time the way one made metallic iron was to take the iron ore and to take charcoal which one made from wood, mix the two, heat them up to the right temperature, and the iron ore becomes reduced to metal. In the 17th century, it became clear that the forests were disappearing. Europe and the British isles had started out as an umbrella of forest, but there was deforestation because people wanted agricultural land; there was also deforestation in order to make charcoal. In the 17th century, many of the British could see the beginning of the end, the beginning of the end of trees, which meant the end of charcoal, which meant the end of metallic iron, unless something new could be introduced.

One single family, a Quaker family, the Darby family, engaged in what must have been one of the first major long-term R & D programs, aimed at learning how to convert coal into a product that would be satisfactory for reducing iron ore to the metal. Coal has a lot of impurities in it, and you can reduce iron ore to the metal with coal directly, but the iron is not satisfactory because of the impurities. It’s not malleable, it can’t be forged into whatever one wants to make. Finally, the Darby family learned how to do this, and produced a product by denaturing coal into what we call coke. This, for the most part, worked; it wasn’t terribly satisfactory but it did work, and this development came just in time, and the British iron industry was saved.

But this placed tremendous demands upon coal and coal mining, and so the British found that they had to dig ever deeper into the ground for their coal. They encountered problems with the groundwater, and so they had to pump out the water. So they made pumps which were pumped up and down by people. And finally, it was found that one could burn coal and make steam, and push the steam against a rotor and cause motion and do work, and thus the first steam engine was born for the specific purpose of pumping out water from the mines. This was refined, and there was a veritable explosion of activy as a result; this was linked to spinning wheels, it was linked to looms, it was linked to the achievement of a variety of tasks, and England became the workshop of the world. The number of inventions produced each year increased exponentially, and this new kind of industrialization jumped the English Channel over to Belgium and to France; it gradually spread eastward, and in spite of everything the British could do to prevent it, it jumped the Atlantic and came to the United States.

The British did everything they could to prevent industrialization from spreading to the colonies, because they wanted to sell us their own manufactured goods and make use of our raw materials. It was forbidden by law to ship over plans from a textile factory, for example; strictly forbidden, but one Joseph [sic] Slater, who must have been one of the first major spies in our modern history, memorized the design of a textile plant, came over here, and built one from memory.[1] He was the Klaus Fuchs of his age. And that got us started on our own path toward industrialization.

We were blessed in the United States with fantastic areas of land, a very fertile land, a low population density. We were blessed by huge quantities of natural resources of iron ore, of copper ore, of coal, of coking coal; and so the situation was ripe for still another explosion which took place on this continent. And indeed, by turn of the century, steel production in the United States was high as it was in any of the European countries. Our own people had taken to inventing a variety of inventions that emerged here, or crossed the Atlantic and were perfected here, and in the meantime, many of these aspects of industrialization had moved farther east still to the Soviet Union and had started to move rapidly into Japan.

Per capita energy consumption income increased steadily. We here were blessed with a great quantity of wood, and until relatively recent times, wood was our largest single source of energy. The use of coal increased greatly, however, with time, and had something still newer not been injected into the picture, we would be a major industrial power today as we are, but instead of being powered by oil we would be powered by coal. The internal combustion engine changed all that, and indeed this was a manifestation that is very similar to many other manifestations of the growth of industry. Technological competitions emerged, where new technologies would appear, they would flourish, they would drive other older technologies into extinction, they would flourish, and still a newer technology would appear, and that in turn would drive still others to extinction. I can illustrate that with a couple of slides—sorry to

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[1] Brown is referrring to Samuel Slater, who emigrated from Belper, Derbyshire, England to New York in 1789 and established a cotton mill from memory. He was recognized in the U.S. as the “Father of the American Industrial Revolution” and in Britain as “Slater the Traitor.”

bother you again here.

Here we have a situation of the United States being powered primarily by clipper ships, by overseas transportation of freight and passengers; mainly by wooden sailing ships. And the population of wooden sailing ships kept increasing and increasing, but in several places, first the steam engine was linked up to the ship, but the wooden ship could not take the forces. So the iron ship was invented, and the steam powered iron ship was so fast, relative to the sailing ship, and it could carry so much, that it drove the sailing vessel into extinction. As you can see the tonnage of sailing vessels went down and down, and the tonnage of steam powered motor ships increased, and finally the sailing ship was driven to extinction. This has many economic advantages: a major one being the decrease of the inventory required, the savings in not having all your goods tied up for such a long time on the transoceanic crossing. And one can see this repeated again and again.

In the United States, on the farm, we use the correct harnesses, so most of our motive power on the farm was through the use of horses and oxen. There was a pretty good ratio, well-established; it took one horse and mule for every four people, to support four people. And indeed, had a commission for the future population of horses and mules in the United States been established by Abraham Lincoln, the presidential commission—it certainly would have been plausible—they would have said, well, by the latter part of the 20th century, there will probably be as many as fifty million horses and mules in the United States. But that did not turn out to be the case, at first because of steam power. We see along around 1870, steam power was introduced to the farm, and it rose very rapidly. A company emerged in Chicago and pushed this very hard; they sold a lot of steamed power stations which powered combines of various sorts, and had things gone on that way—clearly it reduced the rate of growth of the horse population and had its impact—and had it continued that way, it would have driven that horse into extinction on the farm, but still another technology came in: the internal combustion engine.

That rose extremely rapidly starting around 1905 or so; the fact was that the internal combustion engine, applied to the farm, permitted one to do work—it replaced men—in order for human beings to still compete on the farm, they would be paid three cents an hour. The differential was enormous. So there was no competition at all; not only was the horse driven to extinction, so that now there are only a couple of million and most of those are running around race tracks, but human beings on the farm are practically driven to extinction also. That single technological development which involved tremendous inputs of energy into the farm, just tremendous inputs of energy, triggered a variety of very profound social changes in America: first, releasing people from the farm and and moving to the cities; there was both a pushing into the cities because of the decreased work on the farm, and there was a pulling into the cities because of the growing industry. And the industry in turn was fed by increased energy inputs, so on a per capita basis, the energy consumption in the United States increased extremely rapidly.

These migrations of course produced tremendous dislocations, and we… as a result of these migrations, we found ourselves encountering a whole series of difficulties, again, all involving in one way or another changing pattern of energy use. (Could you turn that off now please?) Now, let's look at what some of those patterns were. The internal combustion engine had come on the scene, was introduced into the farm, but also it was introduced to the city in the form of the automobile. And this led us into still another kind of social effect of technological innovations, namely, where a new invention is a novelty; it starts out as a luxury, people bought automobiles for the fun of it, and then gradually society builds itself around the new invention, and what was formerly a luxury becomes transformed into a necessity. We have seen this happen with the automobile as an outstanding example; the telephone is another outstanding example. The net result of all of these changes, of course, is increased energy consumption both on an absolute basis and on a per capita basis.

Now, the cities of the United States had been designed, originally, they emerged originally, with walking in mind, and with horses and carriages in mind, and also with ferry boats in mind, with water transport in mind. The automobile came into the scene and this led to profound dislocations. In the city of New York, for example, it was… it emerged where it emerged because of the ocean shipping and the possibility of shipping things up and down, north and south, around Manhattan on either side by small boats. And most transportation was handled by boats; the farming was done on Long Island and the boats brought the produce over to Manhattan for sale. There was north and south transportation by land, by walking and also by horse-drawn vehicles.

Then the automobile emerged, and that resulted in people finding that they could live away from where they worked; they didn't have to walk to work. They tended to move north; land values changed, and the older areas which originally been inhabited by the rich became slum areas as immigrants were brought in very very rapidly because there was a labor shortage. They had to find places to live; they had very little money, and so they settled in these particular areas. These were, for the most part, Europeans. Then with the spread of the internal combustion engine on the farm, or the mechanization of the farm, that led in turn to enormous Black migrations from the farms into cities. By that time, the original white immigrants from Europe had been assimilated into society; they could pass very easily after the first generation, and so the vacant spots were filled by the Blacks moving in from the farm; again, a push-pull causation. And of course, all of this had profound eventual sociological implications.

For a long time our own oil needs were provided from our own wells. We found oil in Pennsylvania at quite an early time. Initially it was used for oil for lamps, kerosene and the like. With the internal combustion engine, the demand for liquid oil grew very rapidly, and so there were considerable exploration efforts aimed at finding increasing quantities of oil. Many of these were successful. It turned out that we had in the United States two gigantic fields; one in California and the other in the general region of Texas and Louisiana. Oil at that time was pretty expensive, and coal for general use such as power generation, the generation of electric power, was the preferred substance. And of course it was used to power railroads, it was used for heating houses, and most space heating was accomplished with coal. And so even with the automobile growing as rapidly as it did, we were still basically a coal powered society.

Then there was a sequence of events: the Navy started to use oil-powered ships; it was easier to use and could be used more effectively than coal in the powering of ships. Next, it was found that liquids were much easier to handle, basically, than solids. You can move them around and you can handle them automatically more readily, so oil came into use for house heating, and then it came into use for electrical generation. Directly associated with oil, geologically, we find natural gas. Well, natural gas was just thrown away because it is very difficult to carry gas from one place to another, and it was […], just burned. But then we found that we could transport natural gas through pipes. Huge pipelines were built, and natural gas then competed with coal for heating water, for many things… heating houses, and eventually for power generation.

Even so, these were… oil and natural gas were expensive, and it depended markedly on geographic location as to whether these could compete or not. But gradually they did compete, and eventually we found ourselves receiving more of our energy from natural gas than coal. Then a tremendous development took place: namely, the discovery of tremendous deposits of oil in the Middle East. Very few people fully appreciate how ridiculously cheap the oil was. It was so cheap, that for years and years oil could be delivered dockside in the Middle East, ready for shipment, for 10 cents a barrel. Now, nobody got it for 10 cents a barrel, because—I mean, that included profits, by the way. Nobody got it for that because the oil companies found that they could charge what they called rents and they could charge royalties and various other things. Even so we were getting it for a dollar and a quarter a barrel.

This had a profound effect when one couples it with the rapidly improved technology for shipping large quantities of oil across the ocean. This oil greatly accelerated the move away from coal, and for the most part coal disappeared as an energy source in the United States, with a single major exception of producing coke and doing odds and ends of other things. Had things not changed, coal almost certainly would have been driven to virtual extinction as a source of non-metallurgical energy.

Now, this development in the Middle East produced some very interesting political changes. Gradually, the price went up, but it didn't go up very rapidly, but we reached the point where in 1948, a significant development took place. This wasn't widely noticed, but in 1948 for the first time in our history we imported more oil than we exported. And the gap between the two grew and grew quite rapidly. The producers of oil in Texas, Louisiana, and California were very disturbed by all of this, and they were always trying to put taxes and quotas and so forth, in order to prevent this competition. Even so, I remember… the other day I dug out a couple of reports; one was a report of a conference which I attended back in Chicago in 1950 on natural resources. The president was the then president of the board or chairman of the board of the Standard Oil Company of Indiana, Mr. Wilson. He talked about the future of petroleum, and he said unequivocally that we are going to import more and more; that there are vast resources of liquid fuel, crude oil, outside of the United States, but not to fear because they were all securely in American control. And that wasn't so very long ago. He saw nothing wrong with importing, because the Americans had economic control over the whole situation. There were others who were worried, but those worries did not really take hold until much later.

There is also always an argument brewing: how much is really under the ground? It was claimed that there were vast pools of untapped oil in the United States that we just did not know about. It was claimed by some that the resources of oil worldwide were virtually inexhaustible. And it was not until the late 1940s, I would guess, before there began to emerge a really plausible view of what the world situation was really like, and this view was not fully shaped until the mid-1950s as we came to understand how oil came into existence in the first place, the kinds of… when we came to learn better than we did earlier the kinds of places where oil is and where it isn't, and these established guidelines which made it possible for us to assess on a statistical basis. Probably not too badly, how much there really is.

Now, let me show you a few slides that illustrate some of these points. First of all, as time went on and as industry spread all over the world, a fissioning process took place. I call it the fissioning of humanity into two cultures: the culture of the rich and the culture of the poor. And this is well-illustrated when we look at the numbers of people who live at what level of energy consumption. Now, back shortly after the… Well, for the greater part of history you havee always had rich countries and poor countries, but you've always had a lot of people living between. But after World War II, a visible separation started to take place between rich and poor, and that separation has been increasing ever since. You will notice that here we have various numbers of energy consumption, going up by a factor of two. This is a logarithmic scale all referring to the kilograms of coal equivalent that is consumed per person per year, ranging from all the way here from 64, which would be a poor country like Indonesia, all the way up to a consumption of, say, 8 to 16 tons of coal per year, which is the United States, and lots in between, except you will notice that there is almost nothing in here. These are rich nations and these are poor nations, and you get the same kind of bimodal distribution no matter whether you look at steel consumption per person, or per capita gross national product, or what have you. It is a true fissioning process and the characteristics of each of these two groups of nations differ widely from each other. The poor nations are characterized by very rapid rates of population growth, very low consumption of resources per person. The rich nations are characterized by relatively low rates of population growth, but very rapid growth of affluence, and by affluence I mean annual consumption per person and per capita ownership of things. The per capita ownership of things in poor countries is obviously very small.

I was quite surprised when my wife and I moved recently from California to Hawaii. They weigh everything, and I found that we were the proud owners of 16,000 pounds of stuff, not counting any major appliances, not counting the house, not counting the automobile. Just 16,000 pounds of stuff. In my own case, I am an avid collector of books, and that accounted for part of it, but only a part of it. It's just incredible what one accumulates in the course of one's life. The 16,000 pounds was really a residue, after tossing out an incredible amount of stuff, and it gives one a real pause for reflection, because that 16,000 pounds of stuff is reflective, of course, of the amount of energy that was used to produce it in the first place.

This raises the following. What this situation has boiled down to is that each year in the poor countries, 720 million tons of coal equivalent, in oil and other forms of energy, go into the support of two and a half billion people. These areas are proportional to the quantities. In the rich countries, this amount of energy goes each year into the support of 950 million persons. Clearly, to a first approximation, the poor countries are irrelevant from the point of view of their effect upon consumption of resources. Most of the resource consumption and resource depletion in the world today results from the activities within the group of rich nations, and this raises the question then: here we have urban civilization, the industrial transition, and the fissioning process, and what happens given a catastrophe?

And I would suggest that we are dealing here in the industrial part of the world with the classical, resilient, peasant village culture that can withstand tremendous disruption and recover from tremendous disruption; that industrial civilization, meaning Europe, Japan, and North America, we have the tremendous interlocking systems of mines, factories, farms, communication systems, transportation systems, all interlocked with each other. It raises the very real question: how resilient are they? How much disruption [audio skips]… That it could, in principle, be brought to a grinding halt by any one of a number of phenomena, actions or inactions, not necessarily involving war. I suggest that this part of the world in which we live lies in very serious peril of disappearing, and not necessarily from a war. All-out nuclear war is obviously the most serious danger that threatens us, but this can come about in many ways, for a diversity of reasons. Even without war, I think that we can appreciate that this vast system we have created is a very fragile entity.

Let me just cite a couple of examples here. One of the more obvious examples is the blackout of New York in 1965, and repetition of the black out in 1977, except with the added complication the second time around of the human actions involving looting and arson, and just generally bad human behavior. But at the time of the… well, in 1973 the United Kingdom, which was a very complex industrial system in its own right, suffered from a strike of electrical workers so that power lines could not be repaired and generating units could not be repaired. Then the coal miners went on strike, and then they began to get sporadic black outs around the country. Then some of the railroads went on strike, and there was a very precarious situation when completely unpredicted, the Arab oil embargo hit them. This resulted in a tremendous emergency, a national emergency was actually declared; they went on a three-day work week and stayed on a three-day work week for several months, and the British industrial system was on a verge of collapse, total collapse.

In actual fact, in looking back in historical perspective, the actual production in England at the time did not decrease nearly as much as you would have thought *a priori,* and the reason for that is that the British industrial system was so inefficient to start off with that there was a lot of slack in the system. Had that happened in the United States, it would have been curtains, I suspect. But I think such events should give us pause for considerable reflection.

As we will talk about this afternoon, the Japanese were very hard hit when we pulled a soybean embargo on them in 1976. They hadn't anticipated it, and we don't recognize how seriously the Japanese take soy beans. This was a major happening as far as they were concerned, and it had a profound effect which changed U.S.-Japanese relationships dramatically. What I am suggesting is that this system, if it is to remain a system, depends markedly on the smooth flow of the ingredients used to support an industrial society. The unfortunate situation that confronts this at the present time is that if we look at the earth as a whole, there is enough wherewithal to support everybody comfortably, no problem. There's a lot of this, there's a lot of that. If we look at earth as a whole there is no problem. But something known as national boundaries cuts the earth up into 150 chunks, and within each chunk, the people treasure what they call their national sovereignty. Those boundaries between countries slow down, inhibit the flow of raw materials; they slow down and inhibit the flow of manufactured products, of food, of people, of money, of ideas. And so we have then 150 relatively non-resilient systems carved out of what is basically a resilient system, and the consequences of that—we'll come back to that later—are potentially extremely dangerous.

We can see how the per capita consumption of energy in the United States has increased with time in this century. The ups and downs and reflections of economic periods of well-being and depressions—here is the Great Depression—and then the early post-war years, and now we are on a big surge upward, and if the plot continues to go down a bit it's because of the fourfold change in crude oil prices, but it wouldn't go down very much. Now we're on another rise.

It takes the equivalent of burning 12 tons of coal a year to support every individual in our society. It takes less in other societies, but they are getting up there, and the general trend is ever upward. I talked about the competition between energy forms: you can see how coal consumption as a percent of our total consumption of energy increased; that displaced wood which went downhill very rapidly; we see oil coming in at the turn of the century, increasing very rapidly; we see natural gas coming in and the combination of oil and natural gas replaced coal, which went downhill; we see hydropower remaining relatively the same in percentage terms; and we see the emergence of nuclear power, which still represents but a tiny portion of the total. So basically we have become dependent upon oil and natural gas.

One of the reasons for this is the per capita consumption of automobiles. This is the population of automobiles… in terms of population of automobiles per people of driving age. And you see we are approaching 1: in other words, every person of driving age will have a car. After that, presumably there will be a slackening off, but we are getting up there. The Europeans are hell bent in the same direction. I had a very interesting experience before Zhou Enlai's death of spending an evening with him in Peking. I was remarking about all the bicycles in Peking—there are a couple million bicycles there—and he said, Yes, China is never going to become an automotive society. We decided not to be. I said, I've heard that before; and he said, Where? And I said, that's what the Russians told me the first time I visited the Soviet Union. Then I told him about a group of Russian scientists that I hosted in Pasadena in the 1950s. Naturally, they wanted to go out to Disneyland, and I took them to Disneyland. Of all of the fantastic recreational rides you can have there, the one they liked the best is where you get into a miniature car and drive around a miniature freeway. You could hardly get them off of this! They weren't interested in traveling to the moon or anything like that; they wanted the automobile. Today, you can see this in Moscow, and I suspect we will be seeing this in China, unless, of course, there is a crunch. But the curve is heading right toward unity: one car per person.

Let's start looking at quantities. This is the proved reserves of crude oil in the United States. By proved reserves, this means you've drilled there; you have seen it; you're pretty sure you know how much is under there. We look at the contiguous United States… the coterminus United States, the 48 states; we went up and we passed through a peak around 1970, and I would say back in the late forties, early fifties, several of us starting with M. King Hubbert forecast pretty much when that peak would take place. And it did take place. The dotted line is what the proved reserves in the 48 states have been as a function of time since. It's going down and it's going to continue to go down. Now, we were rescued, to a certain extent, by the Alaskan discovery, and so that makes our crude reserve picture higher than it was back in 1970, but the total is going down, and the total is now actually below what our total was in 1970. There isn't all that much oil in Alaska compared with our demands.

Now, the proved reserves are terribly important, because of the nature of the technology of extracting oil from the ground. You dare not pump too fast. If you pump too fast, you jeopardize the total amount that you're eventually going to get out. A pretty good rule is, you don't dare pump much more rapidly than 10 percent of what is under there. So you pump what's under there out during… say, the mean lifetime would be ten years, you pump it out in about ten years. So let's look at the production figures. Here we see—oh, by the way, that peaking of reserves wasn't 1970, it was 1960; I'm sorry. So our total production goes up and and up and up, then we hit a peak, and it's going down. The peak took place in about 1970 and in the contiguous United States it will be downhill all the way; our demands continue to go up, therefore we make up the difference with net imports, and the curve of net imports is going up and up and up, and is continuing to go up.

Let's just look at the levels here. Billions of barrels: production at the peak was 3500 billion barrels a year. If we go back and look at the crude reserves, we see that at the peak here, we are talking about forty billion barrels, that kind of thing. Which is not enough to keep you going for a very long period of time in the face of rapidly increasing demand. Keep in mind, four billion barrels or three and a half billion barrels in production, close to forty billion barrels of crude reserves, again, it's about a factor of ten. You don't dare pump more rapidly than that. Now, we know that there is a lot of oil that hasn't been discovered, but not all that much. Pretty much what will happen is that, again, going back to the reserves, this will settle down into a pretty symmetrical curve. You'll never be out of oil; it'll just keep going downhill and approach zero asymptotically. And it will end up being fairly symmetrical; and with respect to the production itself, this will go down asymptotically and the integral under the curve will correspond to how much was under there originally.

OK. Let's now look at the proved reserves of crude oil in the world. We have not yet hit the peak. We will probably hit the peak within a very few years, the peak of the crude oil reserves.

If we look at production… this is not a real peak, this just went down as a result of the increased price of crude oil on the world market, a factor of four; it's going back up again now. The best guess on the basis of everything we think we know, and by the best guess what I mean is that if I were making a bet, if I were betting a good hunk of money on this: when will the peaking of production take place on a world basis? It will be the year 2000 at the latest, possibly as early as 1990. Now, that means that from that time on, it's going to be downhill, with the need continuing to go up. So what are we going to do? Where are we going to get that energy? Unless we have something to replace it with, in time, then we are going to be in a real crunch that could topple us. Here we've got to keep in mind that we are not dealing simply with one variable. You cannot divorce production of energy and energy needs from food, because most nitrogen fertilizers are made from natural gas or from oil. You can't divorce these energy needs from a whole multiplicity of things, which can also then in turn—you can have a cascading effect—they can interact with each other, and rock the boat, and the boat might sink.

Now here I'd like to summarize the U.S. situation. I stress the U.S. as much as I do because we live here, and also it's more thoroughly studied than any other part of the world, so we know pretty much what the situation is. The crude oil production in 1976 was 2.97 billion barrels; the cumulative production thus far—that's the amount that we have extracted from under the ground—is 118 billion barrels. The proved reserves—again, 1976—is 31 billion barrels; the imports, 1.9, 39 percent of crude oil consumption, refined products, the total being 46% of total petroleum consumption. That's where we stand at the present time with the crude oil production going downhill, with the proved reserves going downhill, and the imports going up. (Would you turn the lights off, please?)

We are finding ourselves a little bit in the position of the anteater. The anteater is a very specialized animal, which eats ants, obviously. But if anything ever happens to the ants, there is not a thing the anteater can do, and it dies. We have specialized on oil to the point that if it runs out, we too are going to die. The real question is whether or not we are going to be able to diversify our sources of energy supply to the point where we can get through this without too much difficulty. Let me say at this point that we need never run out of energy. There is lots of energy available to use. We are blessed with having tremendous quantities of coal in the United States. We are blessed with huge quantities of oil shale. We have lots and lots of uranium; not terribly high grade, but useable. We can utilize geothermal energy; we can utilize solar energy; lots of that available. Wherein lies the problem; why worry? The problem lies in that we are in what I call the energy trap. We have been spoiled by inexpensive crude oil. This trap is a very deep one, because any way you turn is going to cost you more money. People don't like to spend more money, so they procrastinate. They procrastinate making the necessary investments that are needed, coming to grips with the pricing policies that are needed. And we procrastinate, we procrastinate, and we procrastinate. Witness the fact that the Arab oil embargo of 1973—this is 1978—and we in the United States still don't have an energy policy unless no energy policy is a policy.

There are lots of other sources of energy available, but they are not being used, and unless there is a dramatic change in our outlook, they are not going to be used, and we are going to find ourselves in a very precarious position. I think just wishing for a magical technological breakthrough is living in a dream world. True, the prices or the cost of nuclear power can be reduced; the cost of solar power can be reduced; the cose of other energy forms can be reduced. But we've got to keep in mind, these are competing with something that's very inexpensive, even at the inflated… at the present inflated cost.

I remember being at a meeting back in 1974 right after the Arab oil embargo, a meeting at the United Nations. Quite a few Americans were there, and we were meeting with the then Secretary General of OPEC, the Organization of Petroleum Exporting Countries. And the Americans were needling him about this fourfold increase in price. And he said All right, you tell me: What is a resource worth? It's under the ground, you're pumping it out, it's disappearing, it's going to be gone forever. How do you put a price on it? What is it really worth? Simply because you are used to the old price doesn't mean that is really what it is worth. It must be worth more than that. It must be worth at least what you are willing to pay for it, and we haven't really put you to the test yet to find out how much you are willing to pay for it. And basically it's a question of placing a price that is meaningful and realistic on a resource that is disappearing. That's the basic problem which confronts us, and it leads us into very interesting situations. I can give you one example before we have our recess.

We have lots of oil shale. And we know from a technological point of view how to get the carbon compounds out of that oil shale and make liquid fuels. We know how to make liquid fuels out of coal. After all, the Germans lived on it during the war. We know the technology. OK, why don't we do it? Simply because it costs let's say something like twenty dollars a barrel for liquid fuels that are made that way, and we are at present buying crude oil for twelve dollars a barrel. But there's more to it than that. In order to make that twenty-dollar-a-barrel oil from coal, or to make it from oil shale, it's necessary to build a very, very large plant in order to take economy of scale into account, to make use of it. The capital investment required for those plants is billions of dollars. Now, what company is going to go out and build a plant that's going to produce $20 a barrel oil, when you can buy it today for $12 a barrel? Or even let us suppose the Arabs increase the price of their oil to $20 a barrel; what company is going to build that plant knowing that once they get it built, the Arabs might cut the price of oil in order to undersell them?

Clearly, this is a problem that is not going to be resolved in what we call the free play of the marketplace. It's just not going to be solved in that way. It's completely outside the realm of classical interplay of economic forces. And the tragedy of the situation is that the lead time required in order to produce a shale oil plant, so they actually have stuff flowing out of pipes at the other end, or a coal gasification plant, to get it to the point where you actually have fuel going out at the other end, is well over ten years. Between ten and fifteen years. You've got to make the plans, you've got to get the money together, you've got to do all sorts of things. And how much time to do we have before the peak of world production? About that much. So you can see, you can get an idea of what I mean by the crunch that we are in. So something has to give in some way, and if we continue to procrastinate, the give is going to be that we're going to find ourselves in the middle of a tremendous discontinuity which can just knock us for a loop.

Well, I'll stop at this point, and we'll continue later. Thank you very much.

[applause]

[program ends]