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Initiatives for the Future of Energy

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The energy situation is a microcosm of the problems facing the nation. It contains all the elements that deny a straightforward technical solution. Both public and private interests are involved. There is a cost–benefit trade-off between energy supply and environmental quality. Burgeoning demand for energy threatens to deplete basic natural resources, yet conservation has not been a deliberate policy. Tax incentives and import quotas greatly affect the economics of new technology. The energy industry is highly regulated by State and Federal commissions. Their rate structures affect virtually every person and enterprise in the nation. The uses of energy permeate all of our high-technology culture. Any change in supply or demand has profound impacts on the quality of life. National security is involved in fixing the sources of the nation's energy supply. Public argument, not always enlightened, clouds the picture of safety and acceptability of power plants.

There is no doubt that energy usage on an increasing scale is vital to economic health. It seems clear enough that a national goal of high priority is an abundant supply of inexpensive, clean energy. We are not hopelessly far from that goal today, but how are we to achieve it despite the complexities and uncertainties of the next few decades? What role can science and technology play? As is usual, the answers begin to come with the realization that the options available to us for action today are not acceptable for the future. New options are needed and these must come from science and technology. Choosing among the available options at any time also requires science and technology, particularly the social sciences verging into the value system of our society.

For example, we need the option to burn the vast supplies of high-sulfur coal available without the high level of sulfur oxide pollution that goes with it today. We need the option to make the most of our natural uranium supplies and to dispose safely of the lethal wastes that are generated. We need the option of using unconventional power sources such as solar energy. We need the option of developing new natural resources such as oil shale and gas supplies in low permeability rock. We need the option of more efficient conversion from fuel to electricity to keep down thermal pollution. We need the option of burying high-voltage power transmission cable. Last, but far from least, we need what TV commercials might call "the-unheard-of" option; the one we haven't yet conceived. That must come from basic research. From where we are today there are many avenues to be explored. Let me in the remainder of this talk try to set the scene and point to a few directions as potentially providing vitally-needed options.

Some have said that there is an "energy crisis". Others have denied it. I wouldn't care to argue the point, for crises are highly personal perceptions. However, during the past year there have been black-outs, brown-outs or voltage reductions, and potential fuel shortages that have given the public valid concern for their energy supply. The sources of these happenings are many—unreliability of equipment is one, political disturbances in the Middle East another, and a shortage of investment by industry a third. (By the way, the energy industry is one of the most capital-intensive in the economy. It accounts for about 20% of all capital investment in new plant and equipment.) However, the strongest factors in today's energy picture are the opposing influences of growth and the environment.

Energy consumption has grown rapidly during the past 5 years, much more rapidly than earlier, while our concerns for environmental protection have created new, severe demands. After growing at around 3% per year from the Second World War until 1964, total energy growth averaged nearly 5% per year during the last half of the 1960s. Last year, overall energy consumption grew at about 4%. In the last few years, electric consumption has grown at an average annual rate of 7% and in 1968 and 1969 hit 9%.

Thus, projecting future energy needs 30, 20, or even 10 years is a difficult task. Extrapolation from the past is in serious question. Recent energy price increases after years of decrease or stability suggest to some economists that there will be a slowing of growth. Roughly, over the next 30 years, the cumulative demand is likely to amount to $3\text{–}4 \times 10^{18}$ Btu. Perhaps the most difficult question is the effect of environmental and resource limits on energy supply. When one projects the pollution and other environmental problems resulting from today's energy production and consumption technology to 1990 or 2000, the prospects become frightening. The vast amounts of sulfur oxides, particulates, waste heat, and radioactivity that are generated, as well as the land and fuels consumed, lead one to wonder how long such growth can continue without irreversible damage.

It is this potential divergence in energy demand and supply that has created the so-called "energy crisis" and which calls for new options for the future. There is no dearth of opportunity for creating them.

First, consider fossil fuels. Coal, oil, and natural gas supply all but 4% of our current energy needs and will continue to be the dominant source for the remainder of this century at least. At present, the major problems associated with fossil fuels involve air pollution, but the long-term supply picture for oil and gas is worrisome. Current and projected reserves are not adequate to meet future demand by anyone's estimate. Furthermore, oil and gas must supply not only the energy industry but the chemical industry as well, supplying process inputs, lubricants, and transportation fuel. Coal is the most abundant fossil fuel in the United States. There are vast reserves, but coal unfortunately presents the most severe sulfur and particulate problem.

A broad range of R&D areas must be pursued to enable coal to provide its share of our energy needs in the decades to come. The most urgent area involves controlling the sulfur oxides and other air pollutants from stationary combustion sources. Currently, there are no commercially available means of burning high-sulfur coal and oil in accordance with air pollution regulations, as you can read in the April 25, 1971 issue of the New York Times business section. Stack gas-cleaning systems that remove the pollutants from the gas stream are the closest at hand. There are a wide variety of such processes and several of them are now in the large-scale demonstration phase. These processes generally start by reacting the sulfur oxides in the flue gas with another compound in an aqueous scrubber. When limestone is used, the resulting compound, $CaSO_4$, is thrown away, but the other intermediate products are regenerated, producing a marketable sulfur by-product. The results of some of these demonstrations should be available in 3 or 4 years. A good deal of this work is supported by EPA through its National Air Pollution Control office. For Fiscal Year 1972, the program amounts to some $\$25 \times 10^6$.

Unfortunately, all of these stack gas-cleaning processes will add to the cost and complexity of the combustion system and may reduce its efficiency. We therefore need to look at more fundamental changes. The work here is not so far advanced, but there are several promising approaches involving fluidized bed combustion, combined gas turbine–steam turbine cycles, and magnetohydrodynamics (MHD).

Fluidized bed combustion is a different way of burning coal at reduced combustion temperature, facilitating the reaction of sulfur with limestone. The result is expected to be a less expensive boiler, with reduced sulfur and nitrogen oxide emissions.

The combined gas turbine–steam turbine cycle is intended for use with low-Btu gas made from coal at the plant site. The gas is hot-cleaned and burned directly in the gas turbine. Studies indicate that in second- or third-generation designs the low-quality gas can be made from coal in a relatively simple gasification step, the sulfur removed primarily as hydrogen sulfide (rather than SO_2), and the gas used to generate electricity at overall efficiencies approaching 50%. One of the key elements in this high efficiency, which compares with conventional steam cycle efficiencies of about 40%, is the use of high-temperature aircraft technology in the gas turbine. Potential sulfur-removal efficiencies approaching 99%, as compared to the 90% removal expected for stack gas-cleaning processes, are also expected.

MHD is another topping cycle. It converts the kinetic energy in a stream of hot combustion gas directly to electric power with no mechanical moving parts. The very high temperatures (4500–5000°F) involved cause materials problems and may result in significantly more nitrogen oxides than conventional units. Preliminary estimates suggest that advanced MHD plants may approach efficiencies of 60%. Work on all of these advanced concepts is still at a low level of funding by government and industry. More effort is needed, but here we encounter the problems of government funding of commercially-targeted R&D.

R&D in the energy field is particularly vexing in this regard. It is a long and costly road from a theoretical understanding and a laboratory demonstration to a commercially feasible technology. There are at least three recognizable stages culminating in a full-scale demonstration of feasibility. The last two stages, pilot and demonstration plants, are quite expensive and time-consuming. I need only to point out that some 25–30 years passed from the Chicago pile experiment to the commercial nuclear reactors of today. This high cost and deferred pay-off, combined with the fragmentation of the industry, is one of the stickiest points in the energy picture. Clearly, the federal government has an important role to play and close cooperation with industry is a necessity.

Moving beyond electric production to other forms of energy consumption, we find that the cleanest fuels, gas and oil, are in the shortest supply from a resource point of view. Natural gas in particular is clean with respect to its production, transportation, and especially consumption, so it is no wonder that demand has been increasing more rapidly than for other fossil fuels. This trend is expected to continue as new air-pollution standards are implemented. Coal gasification offers the best possibility for augmenting our domestic supplies of clean gaseous fuel. A number of processes have been under development by the Interior Department and industry to convert coal to high-Btu pipeline quality gas. This is a more difficult task than making the low-Btu producer gas needed for combined-cycle power plants I mentioned previously and requires an extensive R&D effort. The Department of Interior is financing a program of coal gasification at $14 million/year.*

Although coal can also be converted to clean liquid fuels, our vast oil shale reserves in the Rocky Mountain area offer the best potential for augmenting our supplies of liquid fuels. For many years people have realized the value of this resource, but because of a number of legal, economic, and technical problems, oil shale is not yet a commercial reality. There are two basic approaches to recovering the shale oil. One can either mine the rock and produce the oil in large retorts or one can try to recover the oil in place. The second approach is more difficult technically but would reduce environmental problems.

Nuclear power offers a means of greatly increasing the nation's supply of clean energy. Over the past two decades we have made a great deal of progress with the light-water converter reactors. These are now on the verge of providing a significant share of electric generation. Safety and many environmental protection systems have been designed into these plants from the start. It therefore troubles me to hear the many objections to individual nuclear power plants being raised when the only alternative is to build additional fossil-fuel plants. In the area of pollution control, nuclear power plants stand far ahead of most fossil-fuel plants. The radioactive discharge systems of all nuclear plants are designed to meet well-established standards, and frequently the actual releases are only a small fraction of these standards. On the fossil-fuel side, the effluent control technology is much less satisfactory. Of course, current generation nuclear plants are somewhat less efficient than fossil plants, so their waste-heat discharge problem is greater. There are some interesting possibilities here, too; for example, reactors employing closed-

* Increased by $10 million in the Presidents' June 4 energy message.

cycle gas turbines could permit the use of much smaller and more esthetically pleasing cooling towers than is possible with the usual steam cycle.

The objections to the disposal of high level radioactive wastes from nuclear power plants also show uneven thinking. The Atomic Energy Commission, with the help of the National Academy of Sciences, conducted extensive studies and tests on the solidification and disposal techniques which are to be used at the salt-mine repository near Lyons, Kansas. There are always some unanswered questions which must be researched, but those associated with high-level radioactive waste disposal seem to me to be of less significance than those such as subsidence and acid mine drainage associated with the mining of coal, for example.

For the future we need to move beyond the current reactors to breeders which will increase the effective utilization of uranium from 1 or 2% to 50 or 60%. This increase means not only that we can make better use of our existing low cost uranium resources, but also that vast quantities of low-grade uranium not economical today would become available to meet the nation's energy needs in the next century and beyond. The United States and many other nations in the world are moving ahead with breeder reactor development programs. Generally the highest priority has been given to the liquid metal fast breeder reactor (LMFBR). In this country we already have several test reactors in operation and are building a large fast-flux test facility. The next logical step is the construction of a large demonstration plant in cooperation with industry to integrate all of the many components in this system. This program is funded through the AEC; in Fiscal Year 1972 a total of $200 million† is allocated.

The breeder reactor is so important to the nation's future energy supplies that we should have a significant back-up effort involving alternative concepts. Currently we are pursuing a small effort on the fast-gas reactor, which uses essentially the same fuel as the LMFBR but a different, perhaps easier-to-handle coolant. The molten-salt concept being pursued at Oak Ridge is fundamentally different and therefore has merit as a completely independent approach. Hopefully, the nation will be able to make additional funds available to pursue these back-up concepts on an expanded basis. As I mentioned earlier, however, the final stages of development can be exceedingly expensive.

While the breeder reactor is expected to become a commercially important energy system in the 1980s, nuclear fusion has great promise for the decades beyond. During the past three or four years significant progress has been made toward the demonstration of the scientific feasibility of controlled fusion. We are still several years away from this elusive goal, but many investigators believe it is finally in sight. After this key step is achieved, we still have the lengthy development process before us. As we found out in the fission reactor business, there are many alternative power systems which look attractive on paper, but materials and other engineering problems are an unmerciful sieve. After a series of small-scale pilot plants, we would then need to move to larger-scale facilities and eventually full-scale demonstration. Based on past practice, I would guess that it will take until about the turn of the century before fusion could become a commercially significant source of power. Its benefits, however, appear to be worth the long effort. Advanced fusion reactors will use the virtually unlimited deuterium found in sea water as fuel, so that fuel supply should not be a problem. Fusion reactors are also expected to generate less radioactive wastes, and if direct conversion is achieved, thermal pollution could also be minimized.

The promise of advanced new power systems is not limited to nuclear energy. Two others of some promise, particularly in certain geographic areas, are solar energy and geothermal steam. We have yet to learn how to convert these to useful electric power on an economical basis, but during the last several years some intriguing possibilities have been suggested. These concepts have a long way to go technically and economically. One cannot say with any assurance that they will prove successful, but I think the nation must investigate these new approaches at least to the point of feasibility.

Less spectacular perhaps than totally new energy systems, but also deserving of attention, are improvements in energy utilization or consumption technology. We should encourage exploitation of the second law of thermodynamics, including improved insulating materials, heat exchangers for recovering energy in exhausts, microwave ovens, thermoelectric refrigeration, thermoluminescent lighting panels and so on. The efficiency of energy consumption is a significant and relatively unexplored dimension.

There are, of course, many other energy technologies which I could have mentioned and which should all be part of a national energy R&D program. Currently, however, there is no such balanced program, although various government agencies and industries are working in a number of the more promising areas. A step toward development of a comprehensive program is the President's proposed reorganization plan which would create a Department of Natural Resources. One of the tasks of this agency would be to formulate a balanced R&D strategy serving both our near and long-term needs for clean energy. It goes without saying, however, that energy R&D defies programming from a single focus. There are, and will continue to be, too many conflicting interests and authorities. This, however, is the shape of the future in many priority fields. Difficulties of this sort often yield to cooperation and compromise between the competing parties. Even logic can play a role. But by far the greatest influence for progress must come from the new options—particularly the unheard-of-options that I mentioned earlier. For these we need the academic community with its insistence on, and tradition of, understanding as a basis for action. NSF will be calling on the universities for this uncommon effort in energy through its new program, RANN. I have great expectations for the coupling so achieved—I'm reminded of H. L. Mencken's saying: "Some problems are so difficult that they cannot be solved in a million years unless some one thinks about them for five minutes." In any case, progress on the energy front will depend on an extraordinary alliance between governments, industries, and the universities.

† Increased by $27 million in the Presidents' June 4 energy message.