Research and development for a fusion economy

Successful realization of the nuclear energy program will be based on the continual development and introduction of ever more efficient types of nuclear technology. The ultimate goal of this effort must be a crash program for thermonuclear fusion power development to guarantee the vast energy and raw materials supplies needed for the next century. The major steps in this program can be achieved by the end of the century if initiated with an investment of approximately lion for advanced nuclear technologies research and development over the next decade.

In the recent past, U.S. government expenditures on advanced research and development have paid off ten to twenty-fold in real economic growth. The result of the NASA program of the 1960s, for example, was a $14 return for every $1 of government investment. A $50 billion investment in nuclear technologies research can be expected to meet or surpass that payoff—in sharp contrast to Carter's recently proposed national energy program which would pour tens of billions into 19th century technologies such as coal gasification.

President Carter has asked the American people and the U.S. Co igress to rubberstamp his $142 billion program for "American energy security." Over 10 years, Carter's plan would pour these billions down the sinkhole of synthetic fuels development and into such economy-wrecking boondoggles as his proposed—and totally incompetent—National Solar Bank.

With a research and development investment of approximately $50 billion in nuclear technologies over the next decade—that is, for merely one-third of Carter's inflationary, economy-wrecking program—America can be put securely on the road to a nuclear future. This investment would aim the U.S. toward the goal of commercialization of thermonuclear fusion power, the technology that can guarantee virtually unlimited cheap energy supplies and vast new supplies of raw materials for the coming decade.

The goals of the nuclear research and development program are these:

1. The completion of the nuclear fission fuel cycle through the use of the fuel breeding reactor and the reprocessing of spent reactor fuel.

2. The further development of high-temperature gas reactors of various sizes and designs and their use—along with high temperature fast beeder reactors—for heat in industrial, chemical, and agricultural applications, and for the preliminary testing of hydrogen production.

3. The development of the fusion-fission hybrid breeder reactor to guarantee sufficiently fast growing amounts of fuel for all types of fission reactors.

4. The construction and testing of the first prototype commercial deuterium-tritium burning fusion reactor.

5. The initial research and development on the use of fusion reactor-grade plasmas for materials processing and extraction.

6. The exploration of a large number of fusion concepts to determine the conditions for burning of so-called advanced fusion fuels which produce electricity directly, with virtually no waste heat or radioactivity.

The benefits of nuclear technology are only secondarily located in its ability to efficiently generate electricity and expand energy supply. The greater economic contribution will come from the increased use of nuclear-derived energy in all forms in integrated combinations of raw materials processing, industrial production, and agricultural applications. This type of integrated nuclear-based production is called a nuplex. The use of hot plasmas from fusion reactors to separate and extract all sorts of raw materials is known as the "fusion torch."

To achieve the enormous economic benefits of nuplex and fusion torch technologies, a balanced combination of large-scale engineering and basic scientific research will be required over the next two decades. These will be made possible by the consolidation of a fully rounded nuclear electrical generating and export industry in the next decade.

The most immediate step to be taken is the removal of the artificial bottlenecks standing in the way of the full-scale operation of the nuclear industry by the standardization and licensing of an adequate number of spent fuel reprocessing plants (such as the facility at Barnwell, South Carolina), the completion of the Clinch River breeder reactor, and the granting of U.S. licenses to foreign (e.g. French) breeder designs. That will also provide the context for solution of the secondary program of waste storage of the nuclear wastes remaining after reprocessing.

With that base, R&D work can proceed on the design and testing of various types of heat and radiation reaction blankets to make full industrial use of the next generation of higher temperature reactors, the high temperature gas reactor and the fast breeders.

The development of the fusion-fission breeder reactor and the first deuterium-tritium fusion can proceed in parallel, based on the most promising fusion reactor types, such as the tokamak. The hybrid can breed new fuel about 10 times faster than the fission breeder, and is absolutely necessary to meet the projected fueling requirements. Likewise, parallel research will be undertaken on the preliminary stages of fusion torch, hydrogen production, and nuplex processing technologies during the next decade. All these areas of R&D will require not only expansion of the nuclear industry but also a vast expansion of R&D inputs from high-technology industries such as aerospace.

The most important area of research, however, will at all times be the fundamental scientific investigations associated with the fusion program. It is still not well understood what sort of plasma conditions are most conducive to the ignition of fusion plasmas and their efficient burnup. The most important clues to the solution of this problem are provided by the many instances of self-ordering pocesses in plasma which cause a profound qualitative change in its physical state. The study of such processes must be at the core of the research program.

The required fusion development program therefore involves the following features: construction and engineering of mainline reactor prototypes; testing of several backup designs; research on alternative concepts, such as the imploding liner; and broad-based fundamental theoretical and experimental investigations of the self-organizing features of plasma processes.

The pace-setting component of the program, the basic research area, requires the development of a qualitatively new type of research facility. This fundamental research center must impart to staff and students a mastery of the actual historical development of the past breakthroughs in mathematical physics, as well as the means for combining theoretical work in mathematics and physics with crucial experimental testing of new hypotheses. As soon as is practical, these centers should be located in every region of the country.

It is this research which will ultimately make it possible to construct highly efficient advanced fuel fusion reactors with full nuplex and fusion torch capabilities. The end result of the nuclear R&D program of this century will be a complete industrial revolution at the beginning of the next century.

The fusion development program

The advanced sector, led by the United States, has the opportunity to begin the massive building of cities centered around nuplexes at the same time that a vigorous international program in research and development is conducted on the frontiers of science.

The foremost need in such a research and development program is the upgrading of the current U.S. fusion program which, as seen in results obtained last August with the Princeton Large Torus tokamak reactor, maintains a leading place in world fusion research. Over the 1980-1990 period, a $50 billion international effort is required to ensure that the world's population will have an inexhaustible source of power into the next century. The commitment to solving the remaining scientific, engineering, and materials problems in fusion and to designing commercial-scale electric-power reactors must be led by the United States.

In the near term, a number of experiments both in magnetically confined and inertially confined fusion will be producing important results that are expected to solve the remaining materials and engineering problems on the road toward developing commercial reactors. The Princeton results themselves showed that the tokamak geometry for magnetically confined fusion was capable of achieving temperatures higher than was required for ignition—44 million degrees Celsius. The next step is to acclerate basic system design and materials development.

It has long been recognized in the scientific community and by the predecessor to the Department of Energy, the Energy Research and Development Administration, that the rate at which scientific and engineering progress can be made in the fusion program depends directly on adequate levels of funding. Yet the U.S. program is now on the lowest and slowest of the fiv funding time tables developed by ERDA: Logic II, which does not see the production of a fusion reactor any earlier than 2015. Logic I does not even provide the funding levels for the program to achieve a commercial fusion reactor.

The following steps must be taken to achieve the most rapid progress toward the large-scale introduction of fusion energy:

• Increase the fiscal 1980 budget allocation by supplemental appropriation to the level required to maintain the construction schedule for the engineering test facilities for both the magnetic confinement and the inertial confinement programs, and begin the design and development work for an engineering power reactor (EPR) by the year 2000.

• This requires an upgrading of the fiscal 1981 budget level as a transition to an Apollo-style fusion program which is necessary to produce the EPR commercial demonstration reactor.

• After the funding requirement is met, the remaining bottleneck in gearing up for a crash program for fusion power development is the inadequate number of trained scientists and engineers that are needed to solve the remaining basic theoretical questions of plasma physics and to build a whole new series of industries that will be required to develop commercial fusion reactors. A brute force educational program, like the one undertaken by NASA, is needed to set up as quickly as possible the fundamental research centers to train the next generation of scientists and engineers in the quantity and quality required.The Fusion Energy Foundation and others in the scientific community have long

What is the fusion torch

With the advent of fusion energy a new technology comes on line for materials processing known as a fusion torch. By exposing materials to the temperatures attainable in a fusion plasma—in the range of tens to hundreds of millions of degrees centigrade—any atomic species can be ionized, have one or more electrons removed from it, leaving it in a charged state. In the presence of electric and magnetic fields, this ionized material can be separated or combined to produce chemically pure materials or fabricate the desired compounds.

The torch uses the high temperature plasma generated in a fusion reactor, preferably of a cylindrical rather than a toroidal configuration. The reactor need not be a net energy producer, but simply capable of sustaining a fusion burn. Part of the plasma is shunted out of the reactor in such a way as to avoid transmission of neutron radioactive contamination, and the material processing occurs in a separate chamber where the plasma is collected.

The implications of this technology are enormous for the potential expansion of natural resources. With the fusion torch and cheap, abundant energy, mining of low grade ore, unfeasible with conventional techniques, is made possible.

It has been estimated that ore processing using the fusion torch can be economically competitive with present methods, even extracting elements from dirt. One of the striking results of this kind of processing is that aluminum, significantly more abundant than iron but more expensive to produce, would become relatively inexpensive and could replace many uses iron now fulfills.

In addition, large amounts of ultraviolet and x-ray radiation can be produced in desired frequency ranges. This energy could be applied to photolytic chemical processing, a technology still to be developed.

Although the concept of the torch has been in existence since the 1960s, there has been only a small amount of theoretical work done to date, and no experimental work.

A crash development program, testing both the magnetic switching and the plasma centrifuge concept for materials separation and the various possibilities for photolytic chemistry should make it possible to add this technology to the industrial arsenal even before the achievement of commercial energy production using pure fusion devices.

recommended that a panel of leading scientists, engineers, and industrial experts be convened to make recommendations to Congress on the organization, structure and funding of an accelerated fusion program to begin in fiscal 1982.

Such a panel has been convened by Rep. Mike McCormack (D-Wash.) who noted in announcing the formation and goals of the panel on June 26: "Nuclear fusion has the greatest potential of any advanced energy technology. If offers a literally inexhaustible and practical energy source—all the energy that mankind can use for all time. Our goal is to have the first commercial demonstration fusion plant on line by the year 2000."

The panel, led by Dr. Robert Hirsch of Exxon Research and Engineering Company, includes scientific and industry experts: Dr. Fowler of Lawrence Livermore Lab, Dr. Furth of the Princeton Plasma Physics Lab, Dr. Trivelpiece of Science Applications, Inc., Robert Smith, chairman of the Board of Public Service Electric and Gas, and Dr. Tihiro Ohkawa from the fusion division of General Atomic Company.

At hearings and closed door deliberations on July 10 and 11, the panel considered recommending a significant increase in fiscal 1980 appropriations for fusion and a 50 to 100 percent increase in fiscal 1981. Rep. McCormack has recommended a $500 million fusion program by FY81.

The fusion budget

To get the nation back on the track as a world leader for growth and development requires nothing short of an Apollo Project centered around fusion research. The nuclear energy development program proposes a total fusion budget of over $6 billion for fiscal year 1981. The bulk is allocated for alternative magnetic fusion systems, and $1.5 billion for inertial confinement research.

These figures are based on past studies done by the Fusion Energy Foundation, updated for 1980 dollars, and on the actual fusion funding in the past three years. The primary source for the magnetic confinement program is the detailed Energy Research and Development Administration study, *Fusion Power by Magnetic Confinement Plan*, Vol. 1-4, ERDA 76/110 (July 1976).

These budget figures for magnetic confinement were arrived at by taking the most advanced ERDA plan in this study, termed Logic V, and adding to the Logic V 1980 budget those funds suggested by Logic V, but not actually appropriated for experimental and engineering facilities in 1978 and 1979.

The projections for the inertial confinement program were made using previous outlines of program plans presented by the Department of Energy's Laser Office, the Lawrence Livermore Laser Division Annual Report for 1976 and consultations with research scientists.

Funding for 10 basic research centers represents a target figure to be authorized, but not spent until the scientific manpower is built up to support a full research program that will back up the mainline fusion efforts.

The fusion budget figures break down as follows:

1) For fiscal year 1980, the budget for both magnetic and inertial confinement fusion must be supplemented by a total of **$220 million**.

2) For fiscal year 1981, the proposed budget is geared toward maximum effective effort with funding for the magnetic confinement program totaling **$2.827 billion** which includes **$1.130**
struction and Engineering (PACE) program for tokamaks; **$377 million** for the PACE program for new engineering facilities; and **$440 million** for alternative concepts PACE.

3) The proposed fiscal year 1981 budget for inertial confinement totals **$1.904 billion** and includes **$1.200 billion** for construction of major projects; **$364 million** to fund operations for major areas of study; and **$340 million** for equipment.

4) Basic research program is to be funded at the level of **$2 billion**.

Hydrogen's role in a nuclear-powered economy

While nuclear-generated electricity and the direct application of process heat will be the principle energy sources for industry and the economy for the future, beginning in the 1990's we will increasingly replace gasoline as the principal liquid fuel for transportation. The best candidate as a substitute for liquid fuels, which will be needed as a petrochemical feedstock, is hydrogen.

There are two major areas of application for hydrogen as a fuel. The first is in the form of fuel cells in transport—automobiles, trucking and buses. The second application is the direct use of hydrogen in standard internal combustion engines, with some modification.

The use of hydrogen as an internal combustion fuel in vehicles has undergone experimental work by the auto industry and others, but the major problem has been the transport and on-board storage of an explosively flammable liquid or gas. Some experimental work on engine modification has been done, but they do not meet economic or performance criteria, at this time.

Much safer and more promising than the transport and storage of hydrogen directly is the use of hydrides. A solid hydride is produced by applying hydrogen under pressure to rare earth metals which absorb the hydrogen gas. As the temperature of the hydride is raised (it is stable at room temperature) the trapped hydrogen molecules are released. This safe source of hydrogen can then be used directly in combustion or in fuel cells which produce electricity directly and can be used for electrical vehicles.

The use of fuel cells using hydrogen has undergone considerable experimental work, both in the U.S. and abroad. The set of electrodes in the hydrogen fuel cell uses ionic hydrogen, activated by a metallic coating on one electrode, in combination with oxygen to produce a direct current. Consolidated Edison is now building a 4.8 MW fuel cell power plant in New York, which will be installed by 1980. The potential conversion efficiency of these fuel cell systems is 65-80 percent.

A major economic problem in the hydrogen economy at the present time is finding a cheap source of the hydrogen itself. After 1990, the availability of fusion-based plasma technologies, hydrogen can be derived through photalysis of water—the use of ultraviolet light to irradiate water. This can be done through the use of any heavy impurity introduced into the fusion plasma.

In the intermediate term, High Temperature Gas-Cooled Reactors, under commercial development in the U.S. and West Germany, can be used in advanced thermo-chemical reactions, now under investigation. The Nuclear Research Center in Juelich, West Germany has been experimenting with this method of "splitting" water.

In the immediate term, methanol can be used as a substitute for gasoline fuels, and can be produced economically as a byproduct process from conventional steel production. In the process developed by a steel industry researcher, Robert Jordan, the input of pure oxygen into the blast furnace and capture of the rich top-gas produced is combined with hydrogen in a reaction chamber to produce methanol. This should be the method of basic blast furnace steelmaking in all new facilities around the world over the next two decades; and in the nuplex, an integrated industrial processing complex, a ready source of liquid fuel would then be produced on-site as methanol.

The U.S. commitment to nuclear power

Since the end of World War II, U.S. industry has exhibited a commitment to a program for rapid implementation of nuclear energy and for international dissemination of the benefits of an increasingly nuclear powered economy.

The rapid development of nuclear energy became the centerpiece of U.S. energy policy, in explicit to-be-implemented terms, with President Eisenhower's proposal for an Atoms for Peace program which he made at the United Nations in December 1953.

On Feb. 17, 1954, Eisenhower sent a message to Congress requesting that the Atomic Energy Act of 1946 be amended to meet the new reality of the mid-1950s. That message read in part:

"Since 1946, there has been great progress in nuclear science and technology. ... The anticipations of 1946 ... have been far outdistanced. In 1946, economic industrial power from atomic energy sources seemed very remote; today, it is clearly in sight—largely a matter of further research and development, and the establishment of conditions in which the spirit of enterprise can flourish.

"... These (atomic weapons secrecy) restrictions impede the proper exploitation of nuclear energy for the benefit of the American people and of our friends throughout the free world."

Eisenhower and the Congress's clear intent in amending the Atomic Energy Act was to create a civilian nuclear industry based on sound American System principles:

"Industry's interest in this field is already evident. ... In amending the law to permit such investment, care must be taken to encourage the development of this new industry in a manner as nearly normal as possible. ... It is essential that this program so proceed that this new industry will develop self-reliance and self-sufficiency."

The conclusion to this Congressional message sums up the general focus of U.S. nuclear policy:

"The destiny of all nations during the 20th century will turn in large measure upon the nature and the pace of atomic energy development here and abroad. The revisions to the Atomic Energy Act herein recommended will help make it possible for American atomic energy development, public and private, to play a full and effective part in leading mankind into a new era of progress and peace."

It need only be mentioned that in 1967 Eisenhower proposed a joint Arab-Israeli development program for the Middle East that was based on the use of nuplexes, nuclear-powered agroindustrial complexes, as part of the solution to the continuing tensions in that area.

Former President Nixon also strongly supported the rapid development of nuclear energy. In his April 18, 1973 Message to Congress on Energy Policy, he stated:

"The major alternative to fossil fuel energy for the remainder of this century is nuclear energy. ... It is estimated that nuclear power will provide more than one-quarter of this country's electrical production by 1985, and over half by the year 2000.

"Most nuclear power plants now in operation utilize light water reactors. In the near future, some will use high temperature gas-cooled reactors. ... At present, development of the liquid metal fast breeder reactor is our highest priority target for nuclear research and development.

"... Every effort must be made by the government and industry to protect public health and safety and to provide satisfactory answers to those with honest concerns about this source of power.

"At the same time, we must seek to avoid unreasonable delays in developing nuclear power.

"Our nuclear technology is a national asset of inestimable value. It is essential that we press forward with its development."

In addition to fostering research of the fast breeder reactor, Nixon was also committed to the development of fusion

"The waters of the world contain potential fuel ... sufficient to power fusion reactors for thousands of years. ... I have proposed in my 1974 budget a 35 percent increase in funding for our total fusion research and development effort to accelerate experimental programs and to initiate preliminary reactor design studies."