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NATIONAL ENERGY PLANNING AND ENVIRONMENTAL RESPONSIBILITY

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America's energy problems, accentuated in recent years by the 1973-74 Arab oil embargo and the frigid 1976-77 winter, result from the nation's prodigious consumption of energy, coupled with its overreliance on dwindling petroleum resources and its underreliance on abundant domestic energy alternatives. The United States can move towards a state of energy self-sufficiency only by pursuing both an aggressive conservation policy and a vigorous energy research, development, and demonstration (RD&D) program. The Energy Research and Development Administration (ERDA) was established in early 1975 to direct the nation towards such a beneficial pattern of energy use and production. This article discusses some of the major elements of ERDA's national energy RD&D plan, and emphasizes the design of energy RD&D alternatives to minimize adverse environmental effects. In October, 1977, all ERDA functions were absorbed by the Department of Energy. Today, ERDA's energy research, development, and demonstration initiatives are being continued within this new organizational framework.[1]

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1 Henceforth in this article, ERDA will be referred to without repeating the fact that in October, 1977, the agency's functions were absorbed by the new Department of Energy. ERDA was created by the Energy Reorganization Act of 1974, Pub. L. No. 93-438, 88 Stat.

I. Background to a Crisis

The people of the United States have long considered limitless energy a birthright. They felled great expanses of forests in the nation's first century. Later, they turned to another abundant material, coal, which soon took over an increasing percentage of the national fuel supply. For most of this century, the United States has relied upon vast quantities of petroleum and natural gas for its energy needs. Now the nation must face a harsh reality: it is drawing too heavily upon the least plentiful resources. Finite oil and gas reserves are rapidly being depleted. Since 1970, domestic production of petroleum has declined steadily and, since 1973, natural gas production has joined in this downward trend. Although the exploitation of Alaskan resources should cause a temporary reversal, it is unlikely that domestic supplies can meet indefinitely a steadily growing demand.[2]

Given these disturbing facts, three courses of action appear open: one, the United States can seek alternative energy resources while decreasing reliance on oil and natural gas; two, it can make up for domestic supply deficiencies by importing; or three, it can do both. So far, the greatest reliance has been placed on the second course, and this has been costly. The quantity of foreign oil imported to the U.S. each year has increased dramatically, to a record high of 47.9% of total petroleum consumption during the first half of 1977.[3] The

1233 (codified at 5 U.S.C. §§5313 *et seq.*, 42 U.S.C. §§5801 *et seq.* (Supp. IV 1974)), and officially commenced operations in January, 1975. In August, 1977, Congress completed action on the bill designed to establish the Department of Energy, and the next day the President signed the Department of Energy Organization Act, Pub. L. No. 95-91, 91 Stat. 565 (1977) (codified at 42 U.S.C. §7253). On October 1, the Department of Energy came into being as the 12th cabinet agency. Along with ERDA, the new department absorbed the Federal Energy Administration, the Federal Power Commission, and elements of a number of other government agencies.

[2] Analyses undertaken within ERDA's *Market Oriented Program Planning Study* indicate that the energy crisis is essentially a liquids crisis. Faced with a depleting domestic resources base, the only new options for oil appear to be oil shale (at approximately present-day world conventional oil prices) and synthetic oil liquids derived from coal (at considerably higher prices). Since only the former is likely to be introduced in the relatively near future, rising petroleum imports coupled with increased prices may have to be borne until alternative energy sources can be developed. *See* ERDA, Market Oriented Program Planning Study, Final Report (ERDA internal memorandum). In contrast, the natural gas situation is potentially manageable to the end of the century. This country produced 20.1 trillion cubic feet of natural gas in 1975, and 19.8 trillion cubic feet in 1976. Production is expected to decrease during the coming years, and then temporarily increase as a result of Alaskan supplies and as a response to higher prices. Today, the U.S. imports about 5% of its annual demand for natural gas.

[3] FEA Monthly Energy Review (part 2, Aug., 1977). *See also* Office of Planning, Analy-

price tag has risen accordingly. Between 1970 and 1976, the expense for imported oil rose from $3 billion to $35 billion per year. The bill for foreign oil in 1977 soared to approximately $45 billion, due, in part, to increased gasoline demand. President Carter has predicted that "unless we act, we will spend more than $550 billion for imported oil by 1985—more than $2,500 for every man, woman, and child in America."[4]

There have also been important changes in the source of our imports. In 1976, the Arab members of the Organization of Petroleum Exporting Countries (OPEC)[5] collectively supplied one third of all U.S. petroleum imports. This represents an increase from a contribution of one fourth of petroleum imports in 1975. Meanwhile, Venezuela's import contribution dropped from 14.3% in 1975, to 11.7% in 1976, and Canada's contribution dropped from 11.8% to 7.2%.[6] Thus, the United States has become more reliant on those countries which embargoed exports of petroleum to this country only a few years back.

These facts demonstrate the importance of reducing our oil and natural gas consumption and aggressively developing alternative energy resources. Only by conservation and fuel substitution can the growing outlays for oil and natural gas be lessened and the spectre of another embargo eliminated.

II. National Energy Planning

ERDA has played a pivotal role in the national drive toward energy independence. During its near three year lifetime, it was responsible for developing new energy technologies and for ensuring their compatibility with the environment. Initially, ERDA's task was the submission of a National Plan for Energy Research, Development and Demonstration to the President and Congress.[7] This plan outlined energy strategies for the near-term (now to 1985), the mid-term (1985 to the end of the century), and the long-term (be-

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sis, and Evaluation, ERDA, 4 Quarterly Report of Foreign and Domestic Developments Affecting Energy (Aug., 1977).

[4] President Jimmy Carter, Energy Address to the Nation, April 18, 1977, Washington, D.C., *reprinted in,* 13 Weekly Comp. of Pres. Doc. 560 (April 25, 1977).

[5] The Arab segment of OPEC includes Iraq, Saudi Arabia, Kuwait, Qatar, United Arab Emirates, Libya, and Algeria.

[6] *See* Office of Planning, Analysis, and Evaluation, ERDA, 4 Quarterly Report of Foreign and Domestic Developments Affecting Energy (Aug., 1977).

[7] ERDA Rep. No. 48 (1975), A National Plan for Energy Research, Development, and Demonstration: Creating Energy Choices for the Future.

yond the year 2000). The original plan was published in June, 1975, and was revised in April, 1976,[8] and again in June, 1977.[9]

On April 20, 1977, within three months of assuming office, President Carter sent a special energy message to a joint session of Congress. In this message, and in the White House publication, *The National Energy Plan,*[10] the President announced seven major national energy goals: (1) to reduce the annual growth of U.S. energy demand to less than two percent; (2) to reduce by half the share of imported U.S. energy; (3) to reduce oil imports to less than 6 million barrels per year; (4) to achieve a ten percent reduction in gasoline consumption; (5) to increase coal production by at least 400 million tons per year; (6) to insulate U.S. residences and buildings; and (7) to use solar energy in more than two and a half million homes. The planning strategies to be used included conservation, increased production and more rational pricing of fuels, a changeover from scarce oil and natural gas to coal and (to the extent necessary) to uranium, and the development of reliable new energy sources.

ERDA was charged with the responsibility for most of the RD&D required by this plan. It was and remains a difficult task. The changeover from oil and natural gas fuels to a broad range of alternative resources is going to take time. Once the fundamental research has been completed for a given energy concept, which might take many years, a pilot plant is generally required. The design and construction of such plants takes from four to six years. The development of a commercial prototype may involve another five to ten years. An equal period of time is generally required before the new technology can achieve a significant market penetration.

In the near-term, national energy planning will emphasize several approaches, including increased conservation, direct utilization of coal and uranium, and enhanced recovery of oil and natural gas. These planning approaches represent technologies which are either already well developed or will require a relatively short period of time before becoming so. Other energy technologies are being developed that will become increasingly important during the 1985-2000,

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[8] ERDA Rep. No. 76-1 (1976), A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future.

[9] ERDA Rep. No. 77-1 (1977), A National Plan for Energy Research, Development and Demonstration.

[10] The National Energy Plan (Apr. 29, 1977) (White House doc.). *See also*President of the United States, Proposed Legislation to Establish a National Energy Policy, National Energy Act, 95th Cong., 1st Sess., H.R. Doc. No. 95-138 (1977).

mid-term period, including geothermal energy, solar heating and cooling, and synthetic fuel production. Nuclear breeder, solar electric, advanced geothermal (hot dry rock and magma), and fusion technologies represent potential energy sources for the 21st century.

III. CONSERVATION

In the spring of 1976, ERDA assigned conservation technologies to the highest national priority category, due in part to delays in developing new energy resources and in part to the need to economize energy.[11] Likewise, the Carter Administration has given particular emphasis to conservation. There are many persuasive reasons for pursuing this goal. Each barrel of oil saved through conservation is one less barrel that needs to be imported. Moreover, increased oil conservation can often reduce imports at less cost than increased oil production, since the cost of improving the efficiency of energy use is generally less than the cost of producing its equivalent amount. Conservation is generally environmentally beneficial, although individual conservation steps may, on occasion, adversely affect occupational or public health. While energy savings can and must be made by improving efficiency, the introduction of energy conservation technology takes time and is limited by such factors as cost, human aspiration, and the laws of thermodynamics.

Numerous opportunities exist for greater efficiency in the use of energy. Some technologies are sufficiently developed to facilitate their relatively quick move into the marketplace. Efficiency opportunities can be divided into three principal categories: transportation, residential/commercial, and industrial.

A. Transportation

The transportation sector of the economy accounts for approximately one quarter of total domestic energy use.[12] Passenger vehicles, such as cars, taxis, and motorcycles, are the largest energy users, currently accounting for nearly 15% of annual domestic en-

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[11] *See ERDA Authorization Fiscal Year 1977, Part I—Conservation: Hearings before the Subcomm. on Energy Research, Development and Demonstration of the House Comm. on Science and Technology,* 94th Cong., 2nd Sess. (1976); *1978 ERDA Authorization: Hearings before the House Comm. on Science and Technology,* 95th Cong., 1st Sess. (1977). *See also* ERDA REP. NO. 76-36 (1976), REVIEW OF THE ENERGY CONSERVATION RESEARCH, DEVELOPMENT, AND DEMONSTRATION PROGRAM.

[12] FEA MONTHLY ENERGY REVIEW (part 2, Aug., 1977).

ergy consumption.[13] The energy-using units in this sector (vehicles) have a much shorter "life" than those in the industrial and residential sectors; thus, in this sector conservation is particularly appropriate. The automotive fleet in the United States is recycled every 10-15 years and, consequently, production changes which improve fuel efficiency can appreciably reduce the national consumption of gasoline in less than a decade.

In the near-term, automotive energy conservation will be achieved through modifications of existing types of vehicles. Smaller, lighter cars with modified engines will provide a good portion of the governmentally mandated improvements in fuel efficiency. Other feasible modifications to present-day cars which can contribute to conservation are computer controlled ignition systems, carburator "lean burn" adjustments for greater air/fuel mix ratios, continuously variable ratio transmissions, lock-up torque converters, and controlled speed accessory drives.[14] Significant progress in many areas of automobile conservation has already been made in the United States, with new car efficiency increasing by approximately 34% from model years 1974 to 1977.[15]

Two new combustion engines, the turbine and the Stirling, hold considerable promise for the mid-term. Both engines involve continuous combustion processes which reduce air pollutant emissions while improving fuel economy. Electric automobiles, which provide a fuel-switching capability rather than a fuel saving *per se*, are also being developed for use as we approach the year 2000.

B. *Residential/Commercial*

The residential/commercial sector accounts for just over one third of domestic energy use.[16] Slightly more than 60%[17] of this sector's energy consumption is used for the heating and cooling of some 70

[13] Based upon calculations from data appearing in STATISTICAL ABSTRACT OF THE UNITED STATES 1976 (Gov't Printing Office 1976).

[14] The continuously variable ratio transmission provides a better match between road load and engine fuel consumption. The lock-up torque converter provides a fourth speed or "overdrive" for automatic transmissions. Once connected, the converter is essentially locked to eliminate slip, thereby duplicating to a large extent the characteristics of a manual transmission. The controlled speed accessory drive operates accessories at a constant velocity, regardless of road or engine speed. This mechanism can save between 5 and 8% in fuel consumption.

[15] *See EPA Releases 1977 Automobile Miles Per Gallon Figures*, ENVIRONMENTAL NEWS (Sept. 22, 1976) (EPA publication).

[16] *See* FEA MONTHLY ENERGY REVIEW (part 2, Aug., 1977).

[17] The National Energy Plan (Apr. 29, 1977) (White House doc.).

million dwelling units and approximately 24 billion square feet of commercial space.[18] Because of the characteristically long life of both residential and commercial buildings, conservation systems which can be retrofitted (furnished with new parts or equipment) into the existing stock of buildings are very important, as are those which can be incorporated into new buildings at the design stage.

One type of energy system appropriate for design or retrofit application is the "heat pump," a device capable of transferring heat from relatively cool areas to other warmer areas by means of a compressible refrigerant. The typical heat pump transfers two to three times the amount of heat per unit of energy as does a conventional electrical resistance heating system. However, because their initial capital cost exceeds that for conventional resistance systems, heat pumps may not be utilized where energy costs can be either deducted as an expense or passed on to a tenant. Attention is therefore being given to increasing the variety of heat pumps, improving their economics, extending their application, and informing consumers of their potential long-term benefits.

Widely publicized energy savers, such as improved insulating practices and materials, can be used in both new and old buildings. The so-called integrated community energy system is another, though more elaborate, energy conserving approach with particular applicability to new residential and commercial complexes as well as to those undergoing extensive redevelopment.[19]

C. *Industrial*

Like the residential/commercial sector, the industrial sector consumes just over one third of all energy used in the United States.[20] Many industrial processes have low energy efficiency ratings (as low as 10% in some direct heating processes) because they evolved during a period of abundant, low-cost energy. Therefore, significant

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[18] *1978 ERDA Authorization: Hearing before the House Comm. on Science and Technology,* 95th Cong., 2d Sess. (1977).

[19] By examining the utility functions required to maintain a given community, including electrical energy for lighting and appliances and thermal energy for space conditioning, as well as waste collection and disposal, and potable water supply, it is possible to combine or integrate functions with energy savings benefits together with reduced environmental impacts and cost reductions. Because communities differ, various technologies for implementing integrated community energy systems are being studied. Some technologies may be more suitable than others in providing the requirements of community programs such as revitalizing a central business district, creating a new development, or undertaking a major redevelopment.

[20] FEA MONTHLY ENERGY REVIEW (part 2, Aug., 1977).

opportunities exist for the development of new energy-efficient processes, but these improvements will no doubt require substantial capital investments.

Two promising and generally applicable industrial energy processes under development are "waste heat recovery" and "cogeneration." Waste heat is produced by a wide variety of industrial processes and equipment. Presently, this energy usually warms adjoining lakes, rivers, and coastal waters, often resulting in adverse ecological impacts. The recovery and harnessing of this energy through waste heat recovery systems could supplement existing energy sources. Cogeneration, on the other hand, is the simultaneous production of electricity and process heat. In 1950, this process supplied 15% of domestic energy; today, the figure has dropped to 4%. Despite this disuse, small generators which simultaneously produce electrical and thermal energy in dispersed cogeneration systems can be less capital-intensive, more efficient, and more environmentally benign than large, central station nuclear or fossil fuel plants. Cogeneration is ideally suited to industrial parks with a mix of facilities which require electrical power and process energy, and which also exhaust substantial amounts of recoverable waste energy. Moreover, cogeneration is adaptable to a number of fuel systems and can substantially reduce the complexity of a facility's overall energy distribution system.

IV. Principal Sources of Energy

The nation's conservation efforts are paralleled by vigorous fuel production efforts and by research into the development of potentially inexhaustible energy sources for use during the upcoming century.

A. *Coal*

Although coal is the most abundant domestic fossil fuel, in 1976, coal supplied only some 18% of domestic energy consumption.[21] Currently coal is being extracted at about the same levels as during World Wars I and II.[22] Coal's relatively poor acceptance is due to a number of factors. First, large amounts of coal are inconveniently situated for extraction and shipment to major markets. Second, the

[21] *See* The National Energy Plan (Apr. 29, 1977) (White House doc.).

[22] U.S. Geological Survey Bull. No. 1412 (1975); P. Averitt, Coal Resources of the United States (1974).

mining and burning of coal have unfortunate health and environmental consequences. Occupational health hazards associated with coal mining include black lung, silicosis, cancer, explosions, falling rock, and tunnel floodings; the burning of coal results in atmospheric pollutants which have been implicated as contributing factors in several human diseases. In addition, the danger exists that the widespread use of coal and other fossil fuels may release sufficient carbon dioxide into the atmosphere to result in a potentially hazardous global warming trend.[23]

Despite these difficulties, coal will probably become an increasingly important element in the domestic energy mix through the near- and mid-terms.[24] Production for 1976 was 665 million tons, compared with 640 million tons in 1975, and 603 millon tons in 1974. President Carter has announced a production goal of at least one billion tons per year by 1985. By the end of the century that figure may rise to 1.8 billion tons.[25]

An improved process known as "fluidized-bed combustion" is now being developed to solve the environmental problems associated with coal burning.[26] This process removes more than 90% of potential sulphur dioxide emissions and reduces nitrogen oxide and particulate matter emissions to levels below those established by the Environmental Protection Agency for new coal burning installations.[27] The fluidized-bed concept, like the conventional process, involves burning coal to produce heat. This heat either boils water to produce steam or heats a fluid contained in tubes. However,

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[23] According to one study, during the last 110 years, the CO2 content of the Earth's atmosphere increased by 11.5% to 13.5% thus reinforcing the belief that further build-up will occur. *See* PANEL OF ENERGY AND CLIMATE, NAT'L RESEARCH COUNCIL OF THE NAT'L ACADEMY OF SCIENCES, ENERGY AND CLIMATE (1977). In fact, it was concluded that the climatic effects of CO2 release could be the primary limiting factor on energy production from fossil fuels during the next few centuries. In response to this problem, ERDA created an Office of Carbon Dioxide Environmental Effect Research within the Office of the Assistant Administrator for Environment and Safety. This new office will develop and carry out research programs as well as interact with other organizations having a scientific or policy interest in the CO2 problem.

[24] See notes 8 and 9, *supra.*

[25] The Federal Energy Administration estimates that coal consumption during the next decade will grow by about 4.8% per year, resulting in a 1985 production of 1.04 billion tons. Most of this forecast increase is expected to occur in the electric utility sector. *See* FEA, NATIONAL ENERGY OUTLOOK, (1976). The *National Energy Plan* later established such an increase as a national goal. The National Energy Plan (Apr. 29, 1977) (White House doc.).

[26] For review of coal technology programs, see ERDA REP. No. 76-10 (1976), FOSSIL ENERGY PROGRAM REPORT, at 15. *See also* ERDA REP. No. 76-63 (1976). FOSSIL ENERGY RESEARCH PROGRAM OF THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION, at 19.

[27] 40 C.F.R. §60D. This standard, promulgated on December 23, 1971, is now being reviewed by the EPA.

unlike the traditional process of burning powdered coal entrained in a jet of combustion air, the fluidized-bed method burns crushed coal mixed with dolomite limestone suspended in slow moving air. The resultant combustion, in the presence of a sulphur dioxide absorber such as limestone, captures the pollutants that might otherwise be released from the burning of medium and high sulfur coal. Hence, from the environmental perspective, the coal burning process can be significantly improved through the use of this new technology.

B. Uranium

America's uranium resources, used in light water reactors,[28] will play a major role both in the near-term and beyond. During the first half of 1977, nuclear plants using these resources produced over 10% of the nation's electricity and about 3% of its overall energy supply.[29] Although forecasts of future capacity vary, ERDA has projected between 330,000 and 380,000 MWe (megawatts electric) of nuclear-generated electricity by the year 2000.[30]

Nuclear systems are attractive for several reasons. First, they not only use domestic rather than imported resources, but they also help conserve limited supplies of oil and natural gas. Second, nuclear-generated electricity is generally cheaper than oil, gas, or coal-generated electricity, and is therefore popular with both utilities and consumers. Finally, nuclear generating plants have excellent environmental and safety records. No individual has suffered injury from a radiation-related accident within the United States commercial nuclear power industry.[31]

Nuclear waste management, on the other hand, presents a more pressing environmental concern: ERDA has estimated that by the

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[28] Light Water Reactors (LWR) use water as the primary coolant/moderator. These reactors are fueled by slightly enriched uranium 235.

[29] See note 9, *supra*. Statistics on total electric power generation in the United States are maintained by the Edison Electric Institute. Also, the nation's utilities provide breakdowns as to how their electricity is generated—hydro, coal, nuclear, etc. Details as to the portion of generated power accounted for by nuclear facilities are maintained by the Nuclear Regulatory Commission and the Atomic Industrial Forum.

[30] DIV. OF REACTOR RESEARCH AND DEVELOPMENT REPORT, ERDA (1977); UPDATE: NUCLEAR POWER PROGRAM INFORMATION AND DATA (1977); Patterson, U.S. Uranium Supply Demand Overview (Jan. 24, 1977) (ERDA paper presented at American Nuclear Society, Executive Conference on Uranium Supply).

[31] Not one radiation related casualty has occurred in the 175 reactor-years of operation during the past two decades. To these 175 reactor-years can be added another 1,400 reactor-years of accident-free operation of naval reactors employed in more than one hundred U.S. Navy surface and submarine vessels.

year 2000, the cumulative high-level radioactive solid wastes produced by commercial nuclear reactors will fill a cube about 20 meters on a side.[32] The most promising technology for handling this waste involves solidifying the liquid wastes into stable forms such as glass, then encapsulating the resultant solids and storing them in stable geologic formations deep within the earth. This approach has received considerable attention,[33] but the necessary technologies have not yet been fully demonstrated. ERDA has launched a program to develop, construct, and operate by 1985 the first of a number of terminal storage repositories. A thorough public review of the program is proposed: first at the end of 1978, when prototype technologies, complete designs, and initial environmental criteria for waste repositories should be developed; and then again in 1981, when licensing of the first repository should be completed.

C. *Enhanced Recovery of Oil and Gas*

Despite the increased use of coal and uranium and despite vigorous conservation efforts, demand for domestic oil and natural gas will remain heavy throughout the century. Thus it will be necessary to maximize extraction efforts from extant and future fields in the continental United States, in Alaska, and offshore the Atlantic, Gulf, Pacific, and Arctic coasts.

Since it is estimated that over two-thirds of the oil discovered in the United States remains unrecovered, new recovery technologies are vitally important. ERDA estimates that these technologies could lead to the recovery of between 0.5 and 2 million barrels of oil per day by 1985.[34] The domestic resource base from which this petroleum is being sought consists of an estimated 290 billion barrels of normal-gravity oil, 107 billion of heavy oil, and 30 billion of bitumen.[35]

Potential sources of new natural gas include gas-bearing shales

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[32] ERDA REP. NO. 76-43 (1976), ALTERNATIVES FOR MANAGING WASTES FROM REACTORS; ERDA REP. NO. 1543 (1976), FINAL ENVIRONMENT STATEMENT: EXPANSION OF U.S. ENRICHMENT CAPACITY; FED'L ENERGY RESOURCES COUNCIL (1976), MANAGEMENT OF COMMERCIAL RADIOACTIVE NUCLEAR WASTES: A STATUS REPORT.

[33] ERDA REP. NO. 76-0701 (1976), PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM ON THE MANAGEMENT OF WASTES FROM THE LWR FUEL CYCLE; Dep't of Energy Release No. R-77-017 (1977), DOE ANNOUNCES NEW SPENT NUCLEAR FUEL POLICY.

[34] ERDA REP. NO. 77-20 (1976), RESEARCH AND DEVELOPMENT IN ENHANCED OIL RECOVERY: FINAL REPORT; ERDA REP. NO. 77-15/1-2 (1976), MANAGEMENT PLAN FOR ENHANCED OIL RECOVERY: PETROLEUM AND NATURAL GAS PROGRAM.

[35] ERDA REP. NO. 76-10 (1976), OIL, GAS AND SHALE TECHNOLOGY.

and associated sandstones, coal seams and the rock surrounding them,[36] and geopressured aquifers.[37] A resource base of up to 3,000 trillion cubic feet may exist for the gas-bearing shales; some 800 trillion cubic feet for the coal seams; and between 5,000 and 50,000 trillion cubic feet for the geopressure reserves.

ERDA is presently participating with industry in 36 principal projects designed to stimulate the recovery of oil and natural gas.[38] These projects include oil and gas recovery by fluid displacement, formation fracturing, and thermal methods.

D. *Solar Heating and Cooling*

The use of solar heating and cooling systems can contribute to reducing long-term consumption of oil and natural gas. In 1975, ERDA estimated that solar energy technology could supply up to 25% of the nation's energy needs by the year 2020, if the costs of collecting and utilizing solar energy could be reduced substantially.[39] This result was confirmed by an economic study conducted two years later.[40] This study showed that by 2020, sufficiently developed solar technologies could provide the energy equivalent of 7.9 billion barrels of oil.

Progress in solar technologies has been substantial, especially since ERDA has worked with other federal agencies to stimulate the development of solar energy systems. In January, 1976, Congress awarded $1 million to ERDA for the installation of 143 residential

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[36] In this context, a coal seam refers to any bed of coal, regardless of its thickness.

[37] Geopressured water reservoirs have been discovered which extend more than 700 miles under the Texas coastal plain from the Mexican border all the way into southeastern Louisiana. They run 50 to 100 miles inland and up to 150 miles offshore. Subsurface exploration has shown that sedimentary rocks at a depth of two or more miles are under-compacted, and thus the fluids they contain bear part of the lithographic load (overburden). When a well is drilled into an average sedimentary formation, the water it contains rises under essentially normal pressure more or less to the surface. In the case of a geopressured zone, however, abnormal conditions alter the result. Heat flowing outward from the Earth's interior passes through the undercompacted sediments and is trapped by overlying impermeable clay beds. The water in the sediments absorbs part of this heat. When geopressured waters flow to the surface through wells, they are not only quite hot, but exert an excess pressure of several thousand pounds per square inch. From such waters, thermal and hydraulic energy can be drawn as well as energy derived from the trapped methane gases.

[38] ERDA REP. NO. 76-10 (1976), OIL, GAS AND SHALE TECHNOLOGY.

[39] ERDA REP. NO. 75-49 (1975), NATIONAL SOLAR ENERGY RESEARCH, DEVELOPMENT AND DEMONSTRATION PROGRAM. *See also* DIV. OF SOLAR ENERGY, ERDA REP. NO. 23A (1976), NONTECHNICAL SUMMARY OF DISTRIBUTED SOLAR POWER COLLECTOR CONCEPTS; DIV. OF SOLAR ENERGY, ERDA REP. NO. SE 102 (1976), SOLAR ENERGY FOR SPACE HEATING AND HOT WATER.

[40] ERDA REP. NO. 77-DSE-115/1 (1977), SOLAR ENERGY IN AMERICA'S FUTURE: A PRELIMINARY ASSESSMENT.

solar units in 27 states. In August, 1976, ERDA selected 34 nonresidential buildings in 22 states and the Virgin Islands for the installation of solar heating and/or cooling systems. By July, 1977, 158 residential and 17 commercial systems were in operation, and 5,331 residential and 166 commercial systems were under contract. The Department of Defense has selected fifty civilian and eighty military residential units for the installation of solar heating and hot water systems. And the Department of Agriculture is testing the application of solar heating to grain dying, food processing, crop drying, greenhouses, and animal shelters.

E. Geothermal Energy

The recovery of energy from geothermal resources could become significant in those regions of the United States where such resources exist.[41] However, commercialization of geothermal processes has been inhibited for a number of reasons, including unavailability of reliable and detailed information on geothermal resources, extraction problems, lack of fluid handling technology, and inadequate knowledge as to potential health and environmental impacts. ERDA has studied these problems, and estimates that roughly 6,000 MWe could be produced by 1985 from domestic geothermal resources, and that this contribution could grow to 40,000 MWe by the end of the century.

Of the various kinds of geothermal resources, only hydrothermal energy is commercially developed.[42] There are two varieties of hy-

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[41] The heat within the Earth is a vast potential source of power if it can be economically utilized. This heat is believed to result from the natural decay of radioactive materials, and is thought to be virtually inexhaustible. Where underground heat sources are relatively close to the surface, they can be—and indeed in some locations for many years have been—tapped for various applications. Geothermal energy comes from a number of sources, including natural steam, hot water, hot dry rock structures, high-temperature molten magma, and geopressured water reservoirs. So far, steam has been used principally to generate electricity, while hot water (with and without steam) has been employed for heating. Research is underway to investigate the feasibility of tapping these other geothermal resources.

Geothermal resources are located in many parts of the world. The "Geysers" in California is the only large, vapor-dominated system that has to date been drilled extensively in the U.S. Another vapor-dominated system is the "Mud Volcano" in Yellowstone Park. For a more in-depth survey of domestic geothermal resources, see White & Williams, Assessment of Geothermal Resources of the United States—1975 (1975) (ERDA Paper).

[42] *See* DIV. OF GEOTHERMAL ENERGY, ERDA REP. NO. 75-87 (1975), GEOTHERMAL ENERGY RESEARCH, DEVELOPMENT AND DEMONSTRATION PROGRAM: DEFINITION REPORT; ERDA REP. NO. 77-9 (1977), GEOTHERMAL ENERGY RESEARCH, DEVELOPMENT AND DEMONSTRATION; ERDA REP. NO. ERHQ-001 (1977), GUIDELINES TO THE PREPARATION OF ENVIRONMENTAL REPORTS FOR GEOTHERMAL DEVELOPMENT PROJECTS.

drothermal energy: vapor-dominated (dry steam containing relatively few water droplets), and fluid-dominated (hot water). Dry steam has been used for some time to generate electric power in the Geysers area of northern California. In many western cities, such as Klamath Falls, Oregon and Boise, Idaho, houses have been heated by hot water wells for many years.

F. Synthetic Fuels

Liquid and gaseous fuels can be generated by converting coal, oil shale, tar sands, waste materials, or biomass[43] into synthetic fuel substitutes. This is an attractive concept because it utilizes not only existing energy resources, but also existing distribution facilities and end-use systems. "Synfuels," as these substitutes are often called, are already being experimentally produced in the United States. Synfuel processes include the liquefaction of coal to yield boiler fuels and crude oil substitutes, the gasification of coal to yield both low BTU and high BTU gas,[44] and the recovery of oil from oil shale, tar sands, waste materials, and biomass.

Oil shale and materials derived from it are chemically complex and contain both organic and inorganic toxins. To evaluate potential risks to humans, scientists expose laboratory animals to these substances and observe them for possible carcinogenic and mutagenic effects. It is too early in the studies to expect results that identify effects on human life.

To deal with environmental problems associated with large-scale synfuel operations, an alternative fuels environmental advisory board should be established. State and local governments would be encouraged to participate in the planning of synfuel plant sites by providing both environmental and socio-economic information.

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[43] Biomass is the formation of carbon-hydrogen compounds through photosynthesis. Biomass includes agricultural and forest residues, certain urban solid wastes, and land and marine energy crops grown and harvested for their energy content. It is estimated that some 200 billion dry tons of biomass are produced annually on planet Earth. Traditionally, biomass has been converted into energy through small wood fires which achieve very low (typically 5%) thermal efficiency. Used efficiently, however, biomass can make a major contribution to our energy requirements. Bioconversion involves first the photosynthetic production of organic matter (biomass) and then its conversion into fuels, heat, and electricity.

[44] Coal gasification can provide a high BTU substitute for natural gas (methane), as well as a lower BTU gas substitute for boiler and other industrial fuels.

G. *Essentially Inexhaustible Energy Resources For The Long Term*

If conservation and the previously discussed energy resources are exploited, we should be able to meet many, it not most, of our energy requirements throughout the near- and mid-terms. But oil, gas, coal, and uranium are in limited supply, while energy sources such as geothermal suffer regional and technical constraints. To provide for America's long-term energy future, we must discover renewable and essentially inexhaustible energy systems.

The most deveoped of these long-range resources is the liquid metal fast breeder reactor.[45] This process is attractive to energy planners because it does not depend on natural uranium, which has a scarce fissionable isotope. However, the breeder reactor's future is uncertain. President Carter, concerned over environmental safety and nuclear proliferation, has restructured the breeder program and has indefinitely deferred a commercial demonstration program.

The earth's sun is an inexhaustible resource whose energy can be harnessed to produce electricity as well as to provide space heating and cooling.[46] ERDA has been active in the development of solar energy systems that collect solar radiation and convert it into both electricity and heat.[47] Presently, two types of such systems are being considered: one, a central receiver system which utilizes a large array of sun-tracking mirrors to concentrate solar radiation on a central thermal collector (boiler); and two, a distributed thermal collector system, which uses numerous small concentrating systems to collect the radiation. During the summer of 1976, the first U.S. built central receiver system was successfully tested at the world's largest solar energy testing facility in Odeillo, France. A central receiver facility is now under construction in the United States. No distributed collector system has yet been tested, although two large-scale distributed collector experiments are presently in design.

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[45] The breeder reactor is a kind of nuclear "furnace" that produces more fuel—in the form of plutonium—than it consumes. Whereas conventional nuclear power reactors use from 1 to 2% of the potential energy in their uranium fuel, breeders can utilize about 60%. *See,* DIV. OF REACTOR RESEARCH AND DEVELOPMENT, ERDA REP. NO. 75-67 (1975), LIQUID METAL FAST BREEDER REACTOR PROGRAM: OVERALL PLAN.

[46] In general, relatively low temperature collector systems are used for the heating and cooling of buildings, intermediate termperature systems are used for process heat, and high temperature systems are used for electricity production.

[47] ERDA REP. NO. 76-159 (1976), SOLAR THERMAL ENERGY CONVERSION; ERDA REP. NO. SE-103 (1976), CENTRAL RECEIVER SOLAR THERMAL POWER SYSTEM: PHASE 1—10-MW ELECTRIC PILOT PLANT.

Other approaches to generating electrical power from the sun involve photovoltaic cells (solar cells) used for energy conversion; wind energy conversion (windmills), and ocean thermal gradient usage, which takes advantage of the temperature differential occurring between the sun-warmed upper levels of the ocean and the colder, deeper levels. The cost of photovoltaic cells dropped in 1976 from $21 per watt to $15.50 per watt. It is hoped that by 1986, the price will be 50 cents per peak watt,[48] thus enabling solar cells to compete in many uses with conventional sources of electric power. ERDA's program of photovoltaic RD&D and market stimulation is designed to increase annual solar cell production from 100 kilowatts in 1975, to 500,000 kilowatts in 1986. Wind systems[49] should become cost competitive in selected regions of the country by the mid-1980's. The United States can achieve annual wind-generated energy production equivalent to 3 to 6 million barrels of oil per year by 1985, and the equivalent of 230 to 410 milion barrels of oil per year by 2000. ERDA's program for the development of ocean thermal energy[50] will include the demonstration of a 100 MWe offshore power plant by 1985, and the fostering of public sector/private sector cooperation in the development of commercially competitive technologies.

While the environmental impacts of these emerging solar technologies are relatively benign, several environmental and safety issues must be considered. Solar thermal electric conversion may affect local water quality and climate; moreover, this process is land-

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[48] Peak wattage is the output of photovoltaic cells in full sunlight under specified conditions. *See* ERDA RELEASE NO. 76-305 (1975), GREATER EFFICIENCY IN LOW-COST SOLAR CELLS ACHIEVED AT UNIVERSITY OF DELAWARE; DIV. OF SOLAR ENERGY, ERDA REP. NO. 76-161 (1976), PHOTOVOLTAIC CONVERSION PROGRAM SUMMARY REPORT.

[49] Winds are generated by the sun; hence, wind systems are properly placed in the solar energy category. Wind conversion systems are essentially large windmills. If present wind energy systems were mass-produced, their costs would be competitive with other forms of energy, at least in high-wind locations. However, industry does not consider the present market large enough to attract the needed development capital. This led ERDA to embark on a cooperative project with NASA to develop a 100-KW system which recently underwent testing at Sandusky, Ohio. While results to date are encouraging, it is evident that much remains to be done in the area of systems economics. The unit is now operating as part of the Ohio Power Company grid in order to gain utility experience. *See* DIV. OF SOLAR ENERGY, ERDA REP. NO. 77-32 (1977), FEDERAL WIND ENERGY PROGRAM.

[50] The enormous quantities of heat stored within the oceans can be converted into electricity by exploiting the oceans' natural thermal gradients. Ocean thermal systems use warm surface water to heat a secondary system liquid, such as ammonia, causing it to expand as a gas and turn a turbine connected to a generator. Then, cold water from the depths of the ocean condenses the ammonia and the cycle is repeated. *See* DIV. OF SOLAR ENERGY, ERDA REP. NO. 76-142 (1976), OCEAN THERMAL ENERGY CONVERSION—PROGRAM SUMMARY.

intensive. Photovoltaic materials may present health concerns to occupational workers during material extraction and cell production; hence, protective regulations may be required. Wind energy towers require special structural considerations, both for operational safety and for reduced television signal interference. In the case of ocean thermal energy conversion plants, the vast quantities of ocean water pouring through condensers and the attendant water evaporation might seriously affect the local marine environment.

Fusion is the most undeveloped inexhaustible energy resource in terms of its potential for commercialization. Since fusion involves combining nuclei rather than breaking them apart, temperatures of approximately 100 million degrees Celsius are required.[51] Fusion will probably not produce any appreciable amount of energy until the beginning of the next century, due to uncertainties concerning its technical and economic feasibility. And, although the desired reaction produces only non-radioactive helium, fusion is not without certain radioactivity problems: first generation fusion reactors will be fueled by radioactive tritium, which in small quantities poses only a relatively mild radiological hazard, but in large quantities may pose a more severe threat.

V. Conclusion

With the advent of the manned space program, the public became aware of what environmentalists had long been saying. Citizens began to realize that unless steps were taken to protect the planet earth, it might some day become unlivable. Apollo 8 astronaut William A. Anders' commentary from lunar orbit in December, 1968, roused the nation's awareness: "I think that all of us subconsciously think that the Earth is flat or at least almost infinite. Let me assure you that, rather than a massive giant, it should be thought of as [a] fragile Christmas-tree ball which we should handle with considerable care."

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[51] The clearest example of fusion is the energy system of the sun. Fusion involves the high speed collision of plasma ions. One of the special properties of plasma gases is that their ions frequently collide with one another; the hotter the plasma gets, the harder they collide. If the plasma's temperature is sufficiently elevated, the ions collide with enough force to overcome their natural tendency to repel each other. When this happens, they combine or fuse to form new nuclei, releasing energy in the process. In the case of a fusion reactor, what is needed is a way to generate a very hot plasma and hold onto it long enough for many fusions to take place, thus releasing the desired energy. *See* Div. of Magnetic Fusion Energy, ERDA Rep. No. 76-110/0-4 (1976), Fusion Power By Magnetic Fusion Energy.

This observation was kept in the forefront of ERDA's early planning and will continue to be emphasized as the functions of the agency are integrated into the new Department of Energy.