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STATUS AND OUTLOOK OF NEW ENERGY RESOURCES AND TECHNOLOGY IN THE U.S.

SUR L'ETAT PRESENT ET LES PERSPECTIVES D'AVENIR DES NOUVELLES RESSOURCES ENERGETIQUES ET DE LEUR TECHNOLOGIE, AUX ETATS UNIS

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Introduction

The President's Fiscal Year 1975 budget emphasizes the need for a continued vigorous short-term (fission) and long-term (fusion) nuclear energy program but also calls for significant expansion of R&D in new energy sources and technology. "New" refers to sources which require modification or conversion to be more useful (e.g., coal liquefaction and gasification) as well as those essentially untapped in the U.S. (e.g., oil shale, solar, and geothermal).

Clearly recognized in U.S. national R&D program planning is the essential role of industry in bringing about the large-scale application of new technologies. Nevertheless, motivated not solely by the current energy crisis but also by a concern that market forces alone may not produce the necessary technical base for expansion of the Nation's energy supply, a strong leadership role has been recommended for the Government. In advance of recent Federal actions, a number of Federal agencies have for several years been undertaking new and expanded energy programs. Thus, for example, the National Science Foundation conducts a rapidly increasing solar energy program and the

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1/ The Budget of the U.S. Government, Fiscal Year 1975, pp. 55-58, U.S. Government Printing Office.

Office of Coal Research (OCR), Department of the Interior, is tripling its staff and research budget to accommodate the authorized growth of coal programs.

In 1971 the Atomic Energy Commission was authorized by an amendment to the 1954 Atomic Energy Act to conduct research in energy fields beyond its traditional nuclear interests. This paper describes several of the new energy programs being carried out by the AEC and discusses their implications in a greatly expanded Federal energy program.

Geothermal Energy

Geothermal energy is a plentiful resource whose industrial use began 70 years ago in Italy. Yet, the total world-wide installed electrical generating capacity based on geothermal resources did not exceed 1000 MW early in 1974. Installed capacity in the U.S. is 400 MW, all of which is associated with a single dry steam field at The Geysers in Northern California.

It is believed U.S. resources could support generation of a significant fraction of power needs as early as 1985. 2/ Exploitation of geothermal resources has not proceeded more rapidly for both technical and non-technical reasons. We will deal primarily with the various resource types and the technology needed for their commercial exploitation.

The geothermal energy resource most easily exploited is dry steam. The technology for utilizing it is well developed and commercial generation of power has been successfully carried out in the U.S. since 1960. There are nevertheless several impediments to more extensive development. The major one is the lack of known reservoirs capable of commercial development. While this may be attributed in part to lack of adequate exploration, it is generally conceded that the existence of such fields in the U.S. is limited. In view of the advanced state of dry steam technology, the government supported geothermal program does not include development work in this area. For most other resources discussed below the AEC is proposing development work leading to construction and operation of a number of demonstration plants in the 10 MWe range.

2/ "The Potential Energy Production from Geothermal Resources" Report of the Subcommittee on Water and Power Resources, U.S. Senate Committee on Interior and Insular Affairs, December 1973.

Hydrothermal convective systems are believed to be far more prevalent than dry steam. In such systems water heated at depth rises by convective circulation to near the earth's surface. Hydrothermal fluids or brines resulting from this process exhibit a wide range of temperatures and composition. At sufficiently high temperatures the brine may flash to a mixture of steam and water in the wellbore resulting in self-pumping of the fluid to the surface. Steam may then be separated from unflashed water and expanded through a turbine to generate electricity in the conventional manner. Thermal efficiencies of 11-12 percent can be expected from plants costing about $275/kW, yielding power in the range of 10 mills/kWh. Electricity is produced in this way in Mexico and New Zealand but not in the U.S.

The most difficult technical problems encountered with high temperature/low salinity convective systems are (1) precipitation or scaling in wells, piping, heat exchangers, and process equipment, (2) environmental disturbances caused by surface discharge of spent geothermal brines and atmospheric venting of noxious gases, and (3) potential seismic and subsidence effects from production and reinjection. One possible solution to the scaling problem is the use of a down-hole pump. This permits the brine to be brought to the surface under pressure and, by suppressing flashing, inhibits scale formation in the well casing and in the heat exchanger.

Brines produced in the Salton Trough region of Southern California and Mexico frequently have salinities (about 250,000 ppm or 25%) which can create severe scaling and corrosion problems, particularly in heat exchangers.

A new approach to power generation with these hypersaline brines is the "total flow" system currently under development by the AEC. 3/ In this system mixtures of liquid brine and flashed steam are brought to the surface and expanded through converging-diverging nozzles to convert thermal into kinetic energy. The brine is then passed through a suitable energy conversion device to produce power. Devices currently being evaluated by industry and AEC include rotating oscillating vane expander, a bladeless turbine, a helical screw expander and a radial inflow turbine. The theoretical thermal efficiency of the total flow system is 1.6 times that for flashed systems. A plant designed on the total flow concept has been estimated to cost less than about $200/kW and to generate power for less than 10 mills/kWh.

3/ "The Total Flow Concept for Recovery of Energy from Geothermal Hot Brine Deposits", A. L. Austin, G. H. Higgins and J. H. Howard, Lawrence Livermore Laboratory, UCRL-51366, April 3, 1973.

Low to moderate temperature (393° and 453°K) geothermal fluids probably constitute the most prevalent hydrothermal systems in the U.S. At these temperatures conversion efficiencies from single flashing steam cycles become economically unattractive. A binary system in which heat is transferred from brine to a low-boiling point working fluid (e.g., isobutane) which is then vaporized and expanded through a turbine could operate at about 12% efficiency at a cost of about $300/kW and generate power at about 10 mills/kWh. Development of binary cycle power plants is underway in the U.S.

The largest geothermal energy resource is believed to be hot dry rock. Its practical utilization has not yet been proven. World-wide interest exists in establishing its feasibility. An exploration program supported by the National Science Foundation is underway to characterize a hot rock anomaly in Montana. The AEC is testing the feasibility of heat extraction from hot dry rock by hydraulically fracturing hot rock and then circulating water through the fractures to extract heat and conduct it to the surface. The technological capability is available but important questions remain unanswered. It must be demonstrated that circulation can be established and maintained without significant loss of fluid; that fractures will remain or can be propped open; that unfavorable geochemical reactions do not occur between water and fresh rock surfaces; and, perhaps most importantly, that extensions of fractured surfaces by thermal stress cracking will produce additional rock surface from which heat may be extracted. Although necessarily very preliminary, estimates have been made that a plant of this type might be built for as low as $300/kW and produce power at about 8 mills/kWh. 4/

Geopressured brines exist over extensive areas along the U.S. Gulf Coast. They are typically found at depths greater than 3000 m at high pressures, 27-41 b/m^2 (4000-6000 psi) at temperatures as high as 453°K, and in association with natural gas and other hydrocarbons. Insufficient data exists to properly evaluate the potential of this resource, but it seems clear that the cost of power will necessarily be greater than for other geothermal resources, due to greater drilling costs. Estimates suggest plant costs of $500-$1500/kW and power costs of 10-30 mills/kWh. These estimates include power from the pressure and heat and credit for 2.64 m^3 of natural gas per m^3 of water (15 cu. ft./barrel).

4/ "A New Method for Extraction of Energy from 'Dry' Geothermal Reservoirs", D. W. Brown, M. C. Smith, and R. M. Potter, Los Alamos Scientific Laboratory, LA-DC-72-1157, July 1, 1973.

While the discussion to this point has emphasized electric power generation, other uses of geothermal heat are practical. In various places in the world it has been shown that geothermal energy may be used for space heating, cooling, process heat, desalination, and agriculture. Since space heating alone accounts for a large fraction of our total energy consumption, development of geothermal energy for such uses could release substantial quantities of fossil fuels for other applications.

Coal Research

The very large gaseous diffusion program, preparing enriched uranium for nuclear power reactors, makes AEC a major coal "consumer". Last year electric power generation (supplied by TVA and private utilities) for the enrichment plants consumed 10.9 million tons of coal. Concern for future fuel availability led to a study 5/ of the alternatives generally facing the coal-fired utility industry in the Eastern U.S. under current sulfur emission standards.

The Clifty Creek power plant in southern Indiana which supplies power to the Portsmouth, Ohio, gaseous diffusion cascade was selected for the study jointly performed by AEC's Oak Ridge National Laboratory, Ohio Valley Electric Corporation, and American Electric Power Source Corporation.

Options considered included purchase of traditional low-sulfur fuels (of low availability and increasing price), application of flue-gas scrubber technology, substitution of low-Btu gas, and hydro-desulfurization of coal. The principal advantage of the latter is that certain desulfurization processes such as catalytic coal liquefaction can produce a synthetic crude oil which is a potential source of transportation fuel. A general status of the technology of coal desulfurization processes is contained in Table 1.

Study results were reported in terms of the increase in power cost associated with various changes in fuel or plant facilities in order to meet emission standards. Two financing cases (fixed charges or capital) were investigated in order to bracket the public and private utility market. The first assumed 100% debt financing using tax-free antipollution bonds, yielding an annual fixed charge rate of 10.1%. The second was based on 55% debt-45% equity financing, giving an annual fixed charge rate of 16.7% which is approximately the rate currently experienced in the utility industry.

5/ Study of Options for Control of Emissions from an Existing Coal-Fired Electric Power Station, R. D. Dunlevy and J. P. Nichols et al, AEC Report ORNL-TM-4298, September 1973.

Table 1 Technological Status of Liquefaction/Desulfurization Processes

Etat Technologique des Procedures de Liquefaction/Desulfuration

Process	Process Developer and Sponsor	Location	Pilot Plants: * Capacity (tons coal/day)	Pilot Plants: Status and Cost	Major Technological Problem Areas	Process Improvement Research and Development
(1) Solvent Refined Coal	Pittsburg and Midway Coal Mining Co. - Office of Coal Research (OCR)	Tacoma, Washington	50	Under construction; startup Nov. 1973; $17 million	(1) Solid separation of unreacted coal (2) Production of H_2 for process (3) Extent of sulfur removal	(1) Solids separation techniques (2) Increased S removal (3) Use of CO + H_2 instead of H_2 for hydrogenation (4) Gasification of unreacted solids for H_2 production
(2) Solvent Refined Coal	Southern Services Co. - Electrical Power Research Institute	Wilsonville, Alabama	6	Under construction; startup Fall 1973; $6 million	(See item 1)	(See item 1)
(3) Meyers Process	TRW, Inc. - EPA	Redondo Beach, California	Bench scale (12-tons/day pilot plant to be built)		Removal of elemental sulfur from the coal after the leach step	Studies of organic sulfur removal by solvent extraction
(4) H-Coal Process	Hydrocarbon Research, Inc.-OCR and group of oil companies	Trenton, New Jersey	3-8 (250-tons/day pilot plant proposed)	Process development unit in operation	(1) Solid separation of unreacted coal (2) Production of H_2 for process (3) Catalyst regeneration	(1) Solids separation techniques (2) Evaluation of catalysts (3) Scale-up to commercial-sized equipment
(5) Consol Process	Consolidated Coal Co. - OCR	Cresap, West Virginia	24	Operated 1967-1970; currently shut down; may be used for coal liquefaction demonstrations	(1) Solid separation of unreacted coal (2) Equipment mechanical problems (3) Production of H_2 for process	(1) Solids separation techniques (2) Mechanical modification of pilot plant to permit continuous operation
(6) COED Process	FMC Corp.-OCR Cogas Devel. Corp. (FMC Corp., Panhandle Eastern Pipeline Co. and Tenn. Gas Pipeline Co.)	Princeton, New Jersey	36	In operation 1970 to date; $4.5 million	(1) Separation of solids from oil produced during oil pyrolysis (2) Gasification of the residual char produced during coal pyrolysis	(1) Development of an oil absorption system to eliminate oil filtration (2) Product evaluation studies (3) Development of char gasification techniques
(7) Bureau of Mines Hydro-desulfurization Process	U.S. Bureau of Mines - Dept. of Interior	Bruceton, Pennsylvania	0.5 (6-tons/day pilot plant proposed)	starting operation	(1) Solids separation of unreacted coal (2) Production of H_2 for the process (3) Scale-up of reactor to commercial sizes	(1) Filter and centrifuge development for solids separation (2) Substitution of H_2 + CO for H_2 used during hydrogenation (3) Determination of catalyst consumption

*FIGURES ARE GIVEN IN SHORT TONS.
1 SHORT TON = 0.907 METRIC TONS.

The study shows (see Table 2) that successful flue gas scrubbing with a limestone slurry could provide the least expensive solution to the power-plant sulfur emission problem while allowing continued use of high-sulfur coal. However, the large cost range for scrubbing reflects the technical uncertainty of the process and suggests it may also be the most expensive option. Only low-sulfur oil or coal will provide a short-term solution to sulfur emission from power plants. At the time of the study (summer, 1973) oil was slightly favored. Recent drastic curtailments of foreign oil deliveries plus large price increases undoubtedly favor low-sulfur coal.

Given the technical uncertainties of limestone slurry scrubbing, Solvent Refined Coal (SRC) is an attractive long-term option. The process is being developed by the Pittsburg-Midway Coal Co. under OCR sponsorship. A 50,000 kg/day (50 ton/day) pilot plant is under construction at Tacoma, Washington.

Low-sulfur fuel oil from coal, produced by catalytic hydrogenation, is more expensive than SRC by approximately 1 mill/kWh. However, its applicability, mentioned earlier, to transportation fuels suggests that its development should be a high priority program and should receive substantial Government support. Currently no pilot plants for catalytic coal liquefaction are under construction in the U.S.

Natural gas can no longer be seriously considered as a utility boiler fuel. Synthetic natural gas (SNG) development was declared a high priority development target in 1971 by the President. Four large SNG pilot plants are currently in various stages of construction and operation. Other concepts are being pursued on a smaller scale in Government laboratories and industry. All involve high temperature reactions with corrosive materials, sometimes under high pressure, and capital costs are quite high. Projected costs for a 7,000,000 m^3 SNG/day plant planned by El Paso Natural Gas Company are approaching $500,000,000 plus perhaps $100,000,000 for mining and coal preparation equipment.

In Situ Coal Gasification

The Lawrence Livermore Laboratory (LLL) has developed a new concept 6/ for an old idea, gasification of coal underground (in situ). The concept is shown schematically in Figure 1.

6/ "A New Concept for In Situ Coal Gasification, G. H. Higgins, AEC Report UCRL-51217, Rev. 1, September 27, 1972.

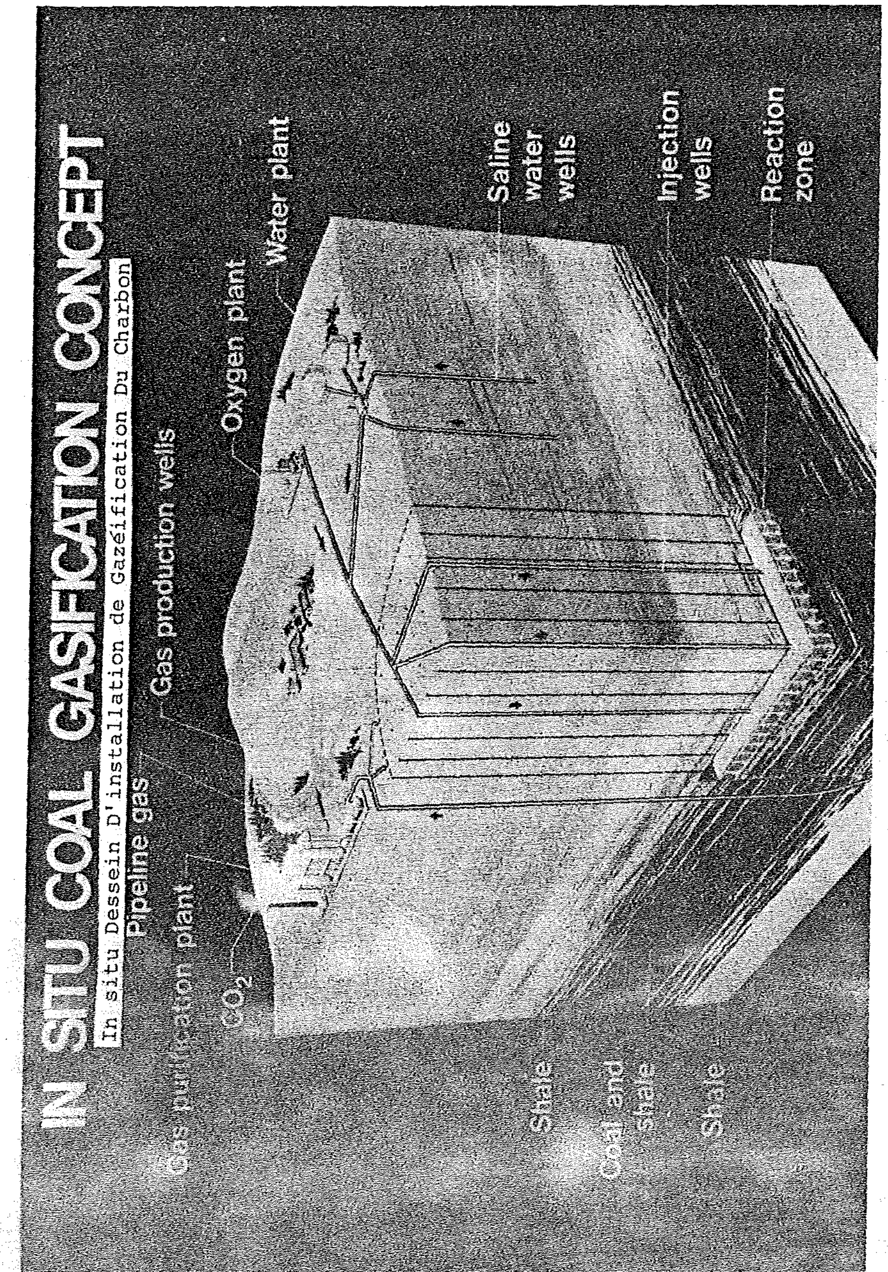

TABLE 2

Estimation Du Coût Additionnel De La Force Motrice Pour Le Rééquipement De Clifty Creek

ESTIMATED ADDITIONS TO THE COST OF POWER FOR RETROFITTING CLIFTY CREEK
(mills/kWh at 90% capacity)

	Near-term 1/ Options		Long-term 2/ Options			
	Low-Sulfur Fuel Oil 3/	Low-Sulfur Coal 4/	Wet Limestone Slurry Scrub.	Low-Btu Gas	Low-Sulfur Fuel Oil from Coal	Solvent Refined Coal
Case 1 (10.1% fixed days)	3.4-4.3	4.0-5.1	2.7-8.1	4.9	4.9-6.0	3.7-5.1
Case 2 (16.7% fixed days)	3.5-4.5	4.1-5.2	3.3-8.5	5.9	5.1-6.2	3.8-5.1

1/ Near-term = capable of immediate implementation

2/ Long-term = requiring significant additional development work before widespread utilization.

3/ Low sulfur fuel oil costs were assumed to be \$4.20-4.80/bbl (\$26.40 - 30.20/m³)

4/ Low sulfur coal costs were assumed to be \$11/ton delivered (\$12.12/metr. ton)

Previous attempts to gasify coal in situ began more than one-hundred years ago, in the shallow deposits of coal in Germany and western Russia. Very low Btu gas ($\sim$3.8 MJ/m³) was produced by air combustion at atmospheric pressure, and much product gas was lost to the formation. The energy yield was also quite low. No economic justification for such processes exists in the U.S. today.

The LLL concept is applied to deep (180-900 m), thick coal deposits and consists first of explosive shattering, yielding perhaps 600 kg of fractured coal per kg of chemical explosives employed. Approximately half of the U.S. coal is covered by at least 300 m of overburden and about 39% is at depths between 300 and 900 m. Coal mining below 300 m is a rarity in the U.S. Consequently, the successful implementation of the LLL concept would make available large quantities of coal presently not being recovered.

After shattering, the coal is gasified by ignition at the top of the broken zone, followed by steam-oxygen injection at several points over the fractured area to produce a stable horizontal planar flame front. The product gas and liquids would be drawn off the bottom of the broken region through a pressure control valve.

The desired reaction is coal plus water to produce methane, and carbon dioxide. Control of the pressure in the reaction zone (using the control valve) to above hydrostatic should exclude unwanted water from nearby aquifers and promote methane formation. However, conversion to synthesis gas (H_2 + CO) followed by surface methanation would be acceptable economically. High pressure operation also may compound one of the most serious technical problems: escape of the reactants and reaction products into the formation.

Preliminary experiments by the U.S. Bureau of Mines at the Hannah coal field in southern Wyoming involving a similar gasification concept but employing air have produced low Btu gas (3.8-7.6 MJ/m³ [100-200 Btu/cu. ft.]) and little methane. No material balance information is currently available.

The process eliminates coal mining and the primary gasifier vessel and thus should be much less expensive than surface processes. It has been estimated 7/ that in situ coal gasification has the potential to produce methane at approximately \$0.50/28.3 m³ (\$0.50/1000 cu. ft.) compared with the earlier estimates of >\$1/28.3 m³ for surface plants. The most important source of reduced cost is the absence of primary gasification process equipment.

7/ "Economic Estimates of the Lawrence Livermore Laboratory Concept of In Situ Coal Gasification", D. R. Stephens, AEC Report UCRL-51340, February 7, 1973.

The environmental consequence of in situ coal gasification should be less than conventional plants. For example, much process heat will be retained in the residual fractured rock (mostly shale) rather than being discharged at the surface. Sulfur will probably be retained by the shale. The most serious consequence should be the eventual subsidence of the land to fill the removed volume of gasified coal.

Energy Storage

When electrical power is used at a constant rate, maximum use is made of high capital cost generating facilities and costs are correspondingly lower. In practice, wide fluctuations in demand necessitates the use of pumped hydroelectric storage installations and gas turbines for generating peaking power. Expansion of pumped storage capacity is limited by the scarcity of suitable new sites and long construction times while gas turbines use scarce fossil fuels inefficiently. Development of new energy storage systems is thus essential to the electric utility industry.

Because of limited alternatives, gas turbine use is growing appreciably, accounting for approximately 20% of U.S. generation capability increase in 1971 aggravating fossil fuel supply problems and power costs (~25 mills/kWh for peaking gas turbines). Increasing numbers of large nuclear plants will further accelerate the need for electric energy storage since economics dictate that reactor systems operate at base loads.

Candidate storage technologies for possible R&D funding include: advanced secondary batteries, use of hydrogen, flywheels, (superconducting magnetic storage) and underground compressed air. Development of the first three could also provide partial or total alternatives to the internal combustion engine for vehicular transportation.

Advanced Batteries. Secondary batteries are of considerable utility interest and have several potential advantages over present methods of meeting peak-power requirements, including: (1) Lower transmission costs. Dispersed location eliminates need to size transmission system for peak loads. (2) Flexible unit size. Batteries can be installed in modular units. (3) Short lead-time. This feature, combined with the modular nature of a battery installation, would allow great flexibility in siting and planning. (4) Low capital investment. Only capacity required in the immediate future need be purchased avoiding capital charges on unused excess capacity. (5) Conservation of petroleum fuels and elimination of dispersed sources of pollution due to reduced need for gas turbine peaking plants.

Although the use of secondary batteries appears highly attractive, presently no commercial battery systems exist capable of meeting the cost, lifetime, and performance requirements. A battery cost of $12-15 kWh (at a 10-hr discharge rate) and lifetimes of 5 years and 1500 charge-discharge cycles would be competitive with existing peaking systems. Lead-acid batteries currently cost about $50/kWh. Advanced lead-acid batteries may prove suitable as an intermediate technology prior to commercial development of the higher specific energy and power systems such as lithium/sulfur and sodium/sulfur. Various other battery systems such as zinc/air, nickel/zinc, zinc/chlorine and molten-salt batteries are also under development, but none of these have reached the stage where their economics and performance for large-scale energy storage applications are known.

Numerous organizations in the U.S. and at least six other nations (USSR, France, Czechoslovakia, U.K., Japan, Switzerland) are engaged in battery research for utility and transportation applications. Much of the work is industrially supported and information on it is limited. The largest development efforts appear to be concentrated on Li/S, Na/S and Zn/Cl_2 systems. The largest U.S. effort on the Li/S system is at the AEC's Argonne National Laboratory (ANL); other Li/S programs are underway at Atomics International and General Motors.

About five U.S. laboratories, including the Ford Motor Company 8/, and a similar number of foreign establishments are working on the Na/S system.

ANL is developing Li/S batteries for off-peak energy storage and transportation applications. A bicell design was selected for the early work. It has Li-Al alloy electrodes at the top and bottom, a central electrode of FeS_2, and operates at about 673K. Other components include a boron-nitride cloth separator, LiCl-KCl electrolyte, a centrally located BN-Mo feedthrough, and a stainless steel housing. This cell design appears capable of achieving a specific energy of 150 Wh/kg, which is the goal for off-peak energy

8/ "Recent Development of the Ford Sodium-Sulfur Battery", Serge Grath, et al, Proceedings of 7th Intersociety Energy Conversion Engineering Conference, September 1972, p.38.

storage. Other design goals include a specific power of 40 W/kg, a 5-year lifetime and 1500 charge-discharge cycles. A full-scale engineering cell was recently operated for 1400 hours and 41 cycles. It achieved a specific energy of 120 Wh/kg in its best cycle and generally ranged between 55 and 90 Wh/kg throughout the first 1100 hours of operation.

While the progress to date has been very encouraging, there is a need to continue to investigate the electrochemistry, to identify and solve materials problems, to design a battery system using low cost materials and to begin to solve problems of insulation, temperature and safety.

Early utility experience with advanced batteries is highly desirable. Design and construction of a battery energy storage demonstration facility on a utility network is a logical next step. Such a facility could be a joint Government/industry venture. Intermediate-technology battery systems such as advanced lead acid could first be installed, to be followed in the late 1970's by more advanced systems such as Li/S or Na/S of about 1 MW power and 10 MW-hr storage capacity.

Hydrogen Storage and Production for Utility Systems. The use of a hydrogen as a promising medium for energy transmission and storage and as a fuel for transportation has received much attention recently. While for the immediate future hydrogen could be derived from fossil fuels, water must be the raw material source for any large-scale use in the future energy economy. Prime attention needs to be given to reducing production costs and developing safe, efficient and economic means for storage. Aside from being a source of heat and motive power, hydrogen can provide electricity via turbines or fuel cells. For seasonal peakshaving requirements it may be stored as a gas in natural gas fields or other suitable natural formations. Storage techniques for more costly peakshaving involve high pressure tanks and liquid hydrogen storage. Costs, safety and environmental effects of these techniques raise sufficient uncertainties to spur the search for new storage techniques.

A promising hydrogen storage system involves the use of metal hydrides (FeTi, Mg, etc.). This permits hydrogen storage in solid form at room temperature at a volume density equal to or greater than liquid hydrogen but at a lower mass energy density. Hydrogen can be released for use in an easily controlled manner by heating. Work on hydride materials is being done at the Phillips Laboratory, Netherlands, and at the Brookhaven National Laboratory in the U.S. At Brookhaven electric utility applications are being investigated. A FeTi-hydride reservoir designed to hold a minimum of 4.5 kg of

hydrogen has been constructed for a storage experiment underway at the Public Service Electric and Gas Company of New Jersey. During the period of peak demand, the hydrogen will be released from the storage reservoir and used to fuel a 12-kilowatt fuel cell. Use of lighter metal (e.g., Mg) hydrides are being investigated for automobile application. Efforts on finding improved and new methods for hydrogen production from water are numerous but are not discussed here.

Flywheels. The use of flywheels for energy storage 9/ has been limited by limitations in energy storage capabilities, efficiency, and hazards associated with catastrophic failure. Advances in materials and mechanical design offer some promise for broader application, possibly for electric utility systems.

Compressed Air. Compressed air pumped storage utilizing underground cavities is being investigated by several utilities. However, large gas turbines (not presently on the market) burning natural or low Btu gas are required. Suitable underground sites appear to be limited. Any significant implementation of this technique will probably await a large-scale coal gasification industry (gas supply) and increasing demands for gas turbines such as those required for use with high temperature gas-cooled reactors.

Superconducting Magnetic Storage. Exploratory studies have indicated superconducting magnetic energy storage may be feasible for utility application. Studies are underway at the University of Wisconsin and at Los Alamos Scientific Laboratory where a 1 megajoule (280 Wh) prototype will be built and tested. Energy density is not as great as for batteries but energy costs may be competitive. Since expected storage efficiency is high (95%) this technique would become more competitive as energy costs increase.

Superconducting Transmission

Moving large blocks of electric power from remote generating plants to urban areas will become increasingly important in the future. Transmission and distribution currently account for about 57% of the total capital investment of the U.S. electric utility industry, hence, cost reductions can have a

9/ Flywheels, Richard F. Post and Stephen Post, Scientific American 229, 17, 1973.

significant impact. Annual U.S. sales of underground transmission systems may reach $2.3 billion by 1990. 10/

Mainly because of environmental considerations, utilities will use underground transmission in many future situations where costs clearly favor overhead transmission. Conventional high capacity underground transmission costs are high (typically > $600/MVA/km); savings greater than $100/MVA/km may be possible with superconducting cables. Cables are currently in service in the U.S. with single circuit ratings up to about 2000 MVA; 500 MVA is more typical. The demand for cables with ratings considerably in excess of those in common usage today could increase dramatically if lower capital cost underground systems were available.

Typically, 10% of generated power is lost in transmission giving a clear incentive for improving transmission efficiency. Superconducting cables could be more efficient than conventional underground cables but there are numerous tradeoffs between capital cost and efficiency. Superconducting systems also promise higher power density than conventional cables.

A specific Federal Government R&D objective is to develop reliable lower cost underground transmission systems capable of matching future overhead systems in both power capacity and voltage. Four U.S. laboratories are currently investigating superconducting transmission; others are involved in closely related work (e.g., cryogenic dielectric phenomena). 11/

The Union Carbide Corp. program, initiated in 1968, was the first large-scale investigation of superconducting power transmission in the U.S. Their design is a rigid concentric tube coaxial system (niobium conductors) with three phases in a common cryogenic enclosure. Electrical insulation consists of pressurized helium with epoxy spacers to support the conductors. Extensive data on the 60 Hz, dc, and impulse breakdown of pressurized cold helium have been obtained. All indications are that helium is a well-behaved dielectric with adequate dielectric strength for this application. Cost figures of approximately $120 to $360/MVA/km for system voltages of 138-345 kV have been quoted. 12/

10/ "Underground Power Transmission", Study Prepared by Arthur D. Little, Inc. for the Electric Research Council, ERC Pub. No. 1-72, October 1971.

11/ "Superconducting and Resistive Cryogenic Power Transmission Research in the U.S.", B. C. Belanger, Paper #J-1, 1973 Cryogenic Engineering Conf., Atlanta, Ga., August 8-10, 1973.

12/ "AC Superconducting Power Transmission", R. W. Meyerhoff, presented at 1972 Applied Superconductivity Conference, Annapolis, Maryland, May 1-3, 1972.

The flexible ac cable being developed by the Brookhaven National Laboratory resembles a paper wrapped conventional cable in many respects. 13/ A hollow conductor consisting of Nb_3Sn tapes on a suitable former will be used. The thin (10 microns or less) niobium-tin superconducting layer is backed by a Cu or Al layer to stabilize the superconductor under fault conditions and provide the necessary mechanical strength.

Before Brookhaven's investigation many people thought the hysteresis losses in niobium-tin would preclude its use in ac superconducting cables. Brookhaven's work not only showed that a viable cable can be designed with commercial niobium-tin tape conductors, but that it is possible to achieve losses much lower than those of existing tapes. Electrical insulation consists of wrapped plastic tapes which in operation are impregnated with the supercritical helium coolant. A dissipation factor of the order of 10^{-5} appears realizable.

In the coaxial Brookhaven design, each phase cable has a grounded outer superconductor wrap over the electrical insulation. All magnetic fields are thus confined to superconducting structures. It is hoped that cable contraction can be accommodated by the spring-like construction of the conductor former, conductor, dielectric wrap, and outer shield conductor. Both rigid and flexible dewar designs are being considered. A flexible cryogenic pipe consisting of nested corrugated stainless steel tubes is being evaluated.

Brookhaven and Long Island Lighting Company have recently completed a joint study which identifies the tradeoffs between conventional and superconducting transmission for moving 4800 MW of power 70 km through a rapidly growing suburban area on Long Island. 14/

The costs for 138 kV and 345 kV superconducting installations were generally consistent with cost projections made previously by Brookhaven and Union Carbide. The cost of a 345 kV double circuit superconducting system was considerably less than that of a multiplicity of conventional pipe type cables. It is encouraging that the double circuit superconducting installation was less than twice the cost of an all-overhead system (5 parallel circuits). Since the reliability of

13/ "Flexible Superconducting Power Cables", E. B. Forsyth, et al, IEEE Trans. on Power Apparatus and Systems, Vol. PAS-92, March/April 1972, p. 494.

14/ "The Technical and Economic Feasibility of Superconducting Power Transmission: A Case Study", E. B. Forsyth, et al, to be presented at the IEEE summer power meeting, Anaheim, Calif., U.S.A., July 1974.

superconducting cables is not well established, a triple circuit 345 kV superconducting system might be required for a first installation and was considered in this study.

Research on ac superconducting transmission is also underway at Stanford University where two areas are being emphasized: dielectric losses at low temperatures and layered superconducting materials.

Work at the Los Alamos Scientific Laboratory indicates that many of the constraints of ac cable design, in particular ac conductor and dielectric losses, do not apply to dc cables. Los Alamos has fabricated sample conductors for their 20 m test bed 15/ by soldering four commercial niobium-tin tapes in parallel on the surface of ordinary copper tubing. Such a conductor carries tens of thousands of amperes of direct current without loss. One interesting question they will explore is the effect of ac ripple current (from the ac-dc conversion process) superimposed on a large dc current.

The Brookhaven ac cable will probably operate in the 6 to 10°K range (supercritical helium). Since superconductors perform better under dc than ac conditions, a Nb_3Sn dc cable might be operated at a higher temperature. Hydrogen forms a two-phase slurry of solid and liquid at about 14°K, which is a possible cable coolant. Los Alamos is considering both helium and hydrogen coolants.

The projects in the U.S. complement each other. Efforts to develop superconducting cables are also underway in Japan, England, West Germany and the Soviet Union. Information exchange between nations is increasing. Plans for joint US/USSR development of prototype cable systems have been formulated.

In view of the degree of world-wide interest and the technical progress being made it is likely that superconducting cables will begin to appear in utility systems during the 1980's and will eventually be an important element of future electric power networks.

Solar Energy

The technical feasibility of using solar energy for terrestrial applications is well established. However, it is diffuse (183 watts/m^2, 24-hour average in the U.S.) and variable (from zero to a maximum and back to zero each 24 hours). The low

15/ "Laboratory Test Apparatus for a Superconducting dc Transmission Line", T. E. McDonald, E. C. Kerr, and W. J. Trela, Paper #C74 201-0, presented at the IEEE-PAS Winter Power Meeting, New York, N. Y., January 27-February 1, 1974.

energy density and variability, combined with the ready availability of fossil fuels, have until now discouraged the development of systems suitable for widespread use. In certain areas, practical systems are already in operation, e.g., domestic hot water heaters, remotely located buoy power systems, house heating systems, and waste conversion plants. Solar energy can be used to generate electric power, to heat and cool buildings and to produce renewable supplies of clean hydrocarbon fuels.

The U.S. national solar R&D program (the National Science Foundation is currently budgeting funds for most of the Federal program) includes six elements: (1) heating and cooling of buildings, (2) solar thermal, (3) bioconversion to clean fuels, (4) photovoltaic, (5) wind conversion, and (6) ocean thermal gradients. Private support of solar energy development is generally restricted to near-term payoff technology such as solar water heaters and space heaters.

The AEC is sponsoring a "Solar Total Energy Community" program at the Sandia Laboratories. 16/ The objective of the effort is to provide a system concept which could save a significant amount of fossil fuel, and be economically competitive with existing energy systems. In this concept, solar energy collected at a central location is used efficiently to provide electricity, space heating and cooling and domestic hot water throughout a community of up to several thousand residential and light commercial consumers. Energy is conserved and costs are reduced by cascading, a process in which high temperature energy is utilized for electrical power production and lower temperature exhaust energy is used for space heating and cooling and hot water heating.

Wind energy has been utilized for many centuries. Based on world-wide experience to date, no major technical barriers to the development of practical systems are foreseen. Reliable and cost competitive wind energy systems need now to be developed. Their substantial application would impact regional and perhaps national energy supplies.

Ocean thermal gradient energy was first demonstrated by Claude in Cuba in the late 1920's. This approach has two significant advantages: (1) energy is collected by the ocean surface, and (2) it is stored in the temperature gradients. However, the economic and engineering constraints appear to be too severe to allow early implementation of this concept.

16/ "The Solar Community and the Cascaded Energy Concept", R. B. Pope and W. P. Schimmel, AEC Report SLA-73-0357, May 1973.

Tidal Energy

Consideration has often been given to harnessing the power in ocean tides. Munk and MacDonald 17/ estimated that about 3×10^{12} watts of tidal energy is dissipated on the earth. Although the potential for developing tidal hydroelectric power is great, very little has been developed principally because of the high cost of constructing dams in deep water where velocities resulting from tides are high. The Rance Project, built in the estuary at the mouth of the Rance River in France, is the only large tidal hydroelectric development in the world. Studies have shown that generally the development of tidal power is not economically justified.

17/ Munk, W. H. and MacDonald, G. J. F., The Rotation of the Earth, a Geophysical Discussion. Cambridge University Press (1960).

SUMMARY

STATUS AND OUTLOOK OF NEW ENERGY RESOURCES AND TECHNOLOGY IN THE U.S.

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U. S. Atomic Energy Commission

A greatly expanded Federal energy R&D program is being undertaken in the U.S. Research sponsored by the Atomic Energy Commission is extending beyond the nuclear field to encompass such areas as geothermal energy, in situ coal gasification, energy storage and superconducting transmission.

Dry steam is presently the only source of geothermal electric power in the U.S. This geothermal resource is the one most readily exploited, but is also the most limited. Hydrothermal fluids or brines can be developed in the U.S. and may yield power at about 10 mills/kWh. A "total flow" system, utilizing a new power conversion device, is being investigated. Fluids in the 393°-453°K range require development of binary power conversion cycles. Experiments on energy recovery from hot dry rock, the largest geothermal resource, are in progress. Development of geothermal energy for nonelectrical uses should also be pursued.

Catalytic coal liquefaction can produce fuels for transportation and utility use. Its development, including pilot plant construction, should proceed with Government support. In situ coal gasification applied to deep, thick coal deposits opens up large potential coal reserves. The process has the potential of producing methane at less than 50% of its cost from surface plants.

Development of new energy storage systems is essential to the utility industry. High temperature secondary batteries (Li/S or Na/S) are being actively developed and may be ready for testing on a utility network at the end of the decade. Hydrogen has long-term potential for energy storage; production costs must be reduced and storage methods devised.

As electrical power demands and environmental concerns continue to increase, superconducting underground power transmission can play an important role in the 1980's and beyond. Both ac and dc cables are being actively developed.

Various solar energy concepts are being pursued in the U.S., one of which would provide for the total energy needs of a small community.

*Consultant

RÉSUMÉ

SUR L'ETAT PRESENT ET LES PERSPECTIVES D'AVENIR DES NOUVELLES RESSOURCES ENERGETIQUES ET DE LEUR TECHNOLOGIE, AUX ETATS UNIS

William O. Doub, Commissaire
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Commission de l'Energie Atomique des Etats-Unis

Les Etats-Unis ont entrepris un programme très étendu de recherches et de developpement dans le domaine de l'energie. Les recherches dirigées par la Commission de l'Energie Atomique s'étendent au delà du domaine nucléaire pour comprendre des domaines tels que ceux de l'énergie géothermique, de la gazéification du charbon, sur place, du stockage de l'énergie et de la transmission par superconductivité.

Jusqu'à maintenant la vapeur sèche a été la seule source de puissance électrique d'origine géothermique aux Etats-Unis. C'est la ressource géothermique la plus facile à exploiter, mais aussi la plus limitée. Il est possible de développer aux Etats-Unis des fluides hydrothermiques ou des saumures qui pourraient produire de la puissance au cout d'environ 10 mills/kWh. Un systeme de "débit total" est a l'étude, qui utilise un nouveau dispositif de conversion de puissance. Les fluides dans le gamme de temperatures de 393° a 453°K nécessitent le développement de cycles binaires de conversion. Des expériences sont en cours sur la récuperation de l'énergie des roches chaudes et sèches; c'est là la ressource géothermique la plus importante. Il faudrait aussi poursuivre le développement de l'énergie géothermique pour une utilisation non-électrique.

La liquéfaction catalytique de charbon peut produire du combustible pour les utilités. Son developpement, ainsi que la construction d'usines pilotes doivent se poursuivre avec l'aide du gouvernement. La gazéification sur place du charbon, dans d'épais gisements de grande profondeur, permetterait l'utilisation d'importantes ressources de charbon. Ce procèdé permet la production de methane a moins de 50% du cout de revient dans les installations du jour.

Il est essentiel, pour les utilités industrielles, de développer de nouveaux dispositifs de stockage de l'énergie. On est en train de développer des piles secondaires à haute temperature (Li/S or Na/S) qui seront peut-être prètes à être essayées sur le réseau dès la fin de cette décade. L'hydrogène offre aussi des possibilités à long terme pour l'accumulation de l'énergie, mais il est nécessaire d'en réduire le coût de production et de trouver des méthodes de stockage.

Alors que les demandes de puissance électrique augmentent, ainsi que le souci de la préservation de l'environement écologique, la transmission de courant par des superconducteurs souterrains peut jouer un rôle important pour les années au dela de 1980. On étudie activement les cables tant pour le courant alternatif que pour le continu.

On developpe aux Etats-Univ diverse methodes de production d'énergie solaire l'une d'elles pouvant produire tout les besoins d'énergie d'une petit communeauté.

*Consultant