BY THE COMPTROLLER GENERAL

Report To The Congress

OF THE UNITED STATES

Magnetohydrodynamics: A Promising Technology For Efficiently Generating Electricity From Coal

If technical problems can be solved, magnetohydrodynamics--which generates electricity from coal by passing heated, electrically charged gases through a magnetic field--could become an important technology for utilities and some industries.

The Department of Energy is just starting tests of equipment at three new larger-than-laboratory test facilities and estimates it will cost about $2 billion through the 1980s to develop and demonstrate this technology.

To improve the effectiveness of the program, the Secretary of Energy should

--evaluate the status of testing at current facilities and its effect on maintaining the technology's pilot plant design schedule,

--analyze the advantages and disadvantages of alternative types of pilot plants, and

--establish a way to actively involve potential users in the program.

The Department agreed with these recommendations.

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COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

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To the President of the Senate and the
Speaker of the House of Representatives

This report discusses the status, potential, and alternative Federal strategies for development of magnetohydrodynamics, a promising technology for generating electricity from coal. It recommends that the Secretary of Energy (1) evaluate the status of testing at current facilities and its effect on maintaining the pilot plant design schedule, (2) analyze the advantages and disadvantages of alternative types of pilot plants, and (3) establish a mechanism for actively involving potential users in the program.

We are sending copies of this report to the Director, Office of Management and Budget; the Secretary of Energy; the Chairman, Tennessee Valley Authority; and interested congressional committees.

Elmer B. Staats
Comptroller General
of the United States

COMPTROLLER GENERAL'S
REPORT TO THE CONGRESS

MAGNETOHYDRODYNAMICS: A PROMISING TECHNOLOGY FOR EFFICIENTLY GENERATING ELECTRICITY FROM COAL

D I G E S T

Magnetohydrodynamics is a promising but relatively unproven technology for generating electricity from coal. Systems using this technology generate electricity by moving super-hot electrically charged gas through a powerful magnetic field.

The strong points of these systems are their potentially high operating efficiencies and low environmental emissions. Their weak points are the many technical problems associated with using coal as their fuel. Commercial-scale systems using coal are still about 20 years away.

As of October 1979 the Department of Energy estimates the Government will have spent about $273 million to develop magnetohydrodynamics and that it will cost about $2 billion through the 1980s to continue to develop and demonstrate the technology. GAO believes the Department must carefully manage the program if it is to effectively develop and commercialize magnetohydrodynamics systems. The Department can improve its program by

--evaluating the status of component delivery and testing at the three U.S. Government testing facilities before making a decision in fiscal year 1981 whether to design a pilot plant.

--analyzing the contribution which a joint Government-industry pilot plant could have on the technology's commercialization.

--establishing a way to actively involve potential users in the Department's program.

STATUS OF PROGRAM

The Department of Energy's two-phased magnetohydrodynamics development program calls for testing at (1) three new larger-than-laboratory United States facilities and numerous smaller facilities and (2) a $372 million pilot plant. DOE recently eliminated plans for a third phase--a $1 billion commercial demonstration facility.

The program is now midway into the first phase. Testing began at one of the new facilities during July 1979 and should begin at the other two during 1980. The Department plans to decide in fiscal year 1981 whether to request congressional approval for preliminary design of a pilot plant. Preliminary design would begin during fiscal year 1984. (See pp. 6 to 8.)

Because the Department plans to use test results from the three new test facilities as the basis for a pilot plant design, testing delays at these facilities could affect the quality of information available to support the design. The Department has already experienced from 2-month to 1-year delays in starting testing at the three facilities. Further delays are possible because of design limitations at one facility. (See pp. 17 to 19.)

GAO believes the Department should strive to maintain its test schedule. Options for minimizing delays in the program include (1) modifying design of the larger-than-laboratory Component Development and Integration Facility, (2) using overtime at that facility, and (3) modifying test plans at the other two new facilities. If more delays occur, however, and these options cannot provide sufficient test results to effectively design a pilot plant, the Department should reexamine the pilot plant schedule. (See pp. 21 to 25.)

Technology development could be accelerated by accelerating and/or skipping pilot plant design and construction. GAO has not quantified the specific risks and benefits of accelerating development; however, based on the unproven status of coal-burning magnetohydrodynamics technology and a previous Federal fossil energy demonstration plant which failed partly because technical problems were not sufficiently ironed out before facility design, GAO believes that the risks of premature design of a major coal burning facility because of insufficient design data are high. (See pp. 25 to 27.)

A decision to adopt this or another approach to accelerate the technology's development should be based on a thorough analysis of the potential risks and benefits.

ALTERNATIVE PILOT PLANT APPROACHES

Before the Government decides whether to request congressional approval for preliminary design of a magnetohydrodynamics pilot plant, the Department of Energy needs to select one of three pilot plant alternatives--a Government-owned-and-operated plant, a joint Government-utility plant, or a Government-industry plant. The Government-owned-and-operated plant offers the advantage of greater Government control of facility test schedules, and the potential for fewer construction delays because of negotiations with non-Government partners. Advantages of the joint facilities include (1) involving users more directly in magnetohydrodynamics development, which could facilitate commercialization, and (2) lower construction costs to the Government. (See pp. 29 to 35.)

A Department of Energy contractor has evaluated the technical feasibility and cost of a Government-utility plant. The Department should also evaluate the costs and benefits of the industrial alternative and compare the advantages and disadvantages of the three approaches before committing to a pilot plant design. (See p. 35.)

USER INVOLVEMENT CAN FACILITATE COMMERCIALIZATION

User involvement can help the Government (1) focus test activities on design of an effective pilot plant and (2) weigh the advantages and disadvantages of the three pilot plant concepts. Direct user involvement in the program is critical to development and commercialization of magnetohydrodynamics and should be encouraged. However, the Department of Energy does not have procedures to systematically involve users in the program and has relied on these users to come to the Department.

RECOMMENDATIONS

To improve the effectiveness of the Department's program, GAO recommends the Secretary of Energy require a report from the Department's Assistant Secretary for Fossil Energy before the 1981 pilot plant design decision which includes an evaluation of

--the status of component delivery and testing at the three new test facilities,

--the advantages, disadvantages, and trade-offs of the use of overtime, design modifications, and other ways to minimize delays in the pilot plant design schedule, and

--the advantages, disadvantages, and trade-offs of a Government-owned-and-operated, joint Government-utility, and a joint Government-industry pilot plant.

GAO also recommends the Secretary establish a mechanism such as periodic regional users' meetings and surveys to actively involve electric utilities and industries that use large amounts of electricity in the program. (See p. 43.)

AGENCY COMMENTS

Copies of the draft report were sent to the Department of Energy and the Tennessee Valley Authority. The Department of Energy agreed with the conclusions, recommendations, and observations concerning the risks of accelerating magnetohydrodynamics' development. The Department also discussed plans to double the size of the pilot plant. Doubling the size of the facility could, in the Department's opinion, accelerate development without increasing its technical risks. However, the Department has not yet completed its analysis of the risks and benefits of this decision. Therefore, it remains to be seen if this approach has merit.

The Tennessee Valley Authority agreed with the report's conclusions and said that (1) the adverse impact of slippages in the program has been mitigated by developments in other coal-burning electric technologies and (2) the incentive may not exist for industrial-size magnetohydrodynamics systems because smaller industrial systems might not be as efficient and cost effective. The Authority also suggested the report expand and update its discussion of environmental considerations. This section of the report has been revised accordingly. (See p. 43.)

Contents

ABBREVIATIONS

CDIF	Component Development and Integration Facility
DOE	Department of Energy
EPRI	Electric Power Research Institute
GAO	General Accounting Office
MHD	magnetohydrodynamics
TVA	Tennessee Valley Authority
U.S.S.R.	Union of Soviet Socialist Republics

CHAPTER 1

INTRODUCTION

Magnetohydrodynamics (MHD) is one of many technologies being developed by the Department of Energy (DOE) to generate electrical energy from coal--the Nation's most abundant fossil energy resource. MHD holds the promise of generating electricity more efficiently than current and most advanced coal technologies with a minimum of environmental problems. The technology is, however, still in the early stage of development and many technical problems still need to be resolved. Its ultimate contribution to the Nation's electricity supply will depend on successful resolution of these problems and on MHD's economic and environmental performance compared with other electric generating technologies.

For fiscal year 1980 DOE requested $72.0 million for MHD-related research and development activities. MHD is DOE's third largest fossil energy research and development program and constitutes about 10 percent of the Department's total fiscal year 1980 fossil energy request. Only the coal liquefaction and the coal gasification programs represented larger proportions of DOE's fiscal year 1980 $662.7 million fossil energy budget request.

This report focuses on one of two types of MHD technologies--open cycle MHD. 1/ Open cycle MHD technology is more developed than closed cycle MHD and receives about 98 percent of Federal MHD research funds.

The report discusses

--the status and potential of open cycle MHD systems,

--the management of DOE's current open cycle MHD test program,

--alternative strategies for developing open cycle MHD, and

--the involvement of users in the open cycle MHD program.

1/How the open cycle MHD process works and the differences between open and closed cycle MHD systems are discussed in ch. 2. Unless otherwise noted, MHD as referred to in this report will mean open cycle MHD.

The report does not examine the implications of alternative budget levels for the MHD test program.

Among foreign countries, the Soviet Union is most active in MHD research and development. This report also discusses the Soviet Union's MHD program and compares it with DOE's program. The report, however, does not evaluate the merits of the Soviet Union's approach to MHD development.

SCOPE OF REVIEW

The report is based on information obtained during interviews with (1) DOE and contractor officials in Washington, D.C., Butte, Montana, and other locations and (2) representatives of the Electric Power Research Institute, the Tennessee Valley Authority, 16 electric utility companies, and 12 major energy-consuming industrial companies. We also reviewed publications, studies, and DOE program documents as of January 25, 1980, related to MHD development and commercialization. A list of utility and industrial firms contacted during the review is included as appendix I.

CHAPTER 2

MHD CAN BECOME A MAJOR ELECTRICITY GENERATING TECHNOLOGY--IF TECHNICAL PROBLEMS CAN BE SOLVED

Magnetohydrodynamic electric generating systems are a promising future option for the Nation's electric utilities. The 1977 Energy Conversion Alternatives Study and a 1979 Electric Power Research Institute study projected that, if economic MHD systems can be developed, MHD's high efficiency will make it the technology of choice for electric utilities after 2000. However, the technology is completely new. Future MHD systems would generate electricity using scientific principles which, although theoretically sound and accepted, are not used by utilities today. New MHD-related equipment and materials must be developed and tested if the technology is to be accepted and used.

The United States is just now building and beginning to test coal-burning MHD systems in larger-than-laboratory-size test facilities. Because of the technical problems still facing MHD coal-fired systems and the status of testing of these systems, most electric utilities and potential industrial users of MHD are only cautiously optimistic about MHD's future.

HOW THE MHD PROCESS WORKS

The basic scientific principle behind MHD--and conventional electric powerplants--is relatively simple: move a conductor through a magnetic field to create electricity. It is the next scientific principle--the type of conductor used--and the size of the magnetic field which distinguish MHD from conventional technology. In a conventional steam powerplant, electricity is generated after steam rotates a turbine which then moves copper wires through a magnetic field. MHD systems, in contrast, generate electricity by moving a super-hot, electrically charged gas through an extremely powerful magnetic field. To do this efficiently, new MHD equipment and materials must be developed to (1) produce the super-hot, electrically charged gas, (2) collect and extract the MHD-generated electricity, and (3) remove chemical particles and coal wastes (called slag) from MHD's exhaust gas so that its waste heat can be used again.

Because MHD's waste heat would still be hot enough to produce steam, MHD systems are being developed to work with conventional steam-driven electric generating technologies.

Thus, a combined MHD/steam powerplant will produce electricity in two ways--in the higher temperature MHD portion, often called the MHD "topping cycle" of the plant, and in the lower temperature steam, or "bottoming cycle," of the plant. Figure 1 illustrates a simplified version of such a combined powerplant. The MHD/steam process would begin by burning coal 1/ with air which has already been heated to about 2,500 degrees Fahrenheit, and adding particles or "seeds" of a chemical (such as potassium carbonate) to the combustion gases. The resulting electrically charged, 5,000-degree Fahrenheit gas then passes through a box-like channel lined with electricity extraction equipment and surrounded by a powerful magnet. It is within this channel that electricity is first produced--as the electrically charged gas moves through the channel and interacts with the magnet's forces. After equipment lining the inside walls of the channel collects this electricity, the MHD gas passes through equipment outside the channel which (1) slows down the gas, (2) recovers and reprocesses potassium in the gas, and (3) uses heat from the gas to generate steam. The process is completed when this steam is used to drive turbines in the plant's steam bottoming cycle to create electricity a second time. The MHD-generated and steam-generated electricity are independently prepared for transmission and supplied to the utility's electric transmission lines or an industrial user. 2/

STATUS OF MHD DEVELOPMENT PROGRAMS

MHD systems to generate electricity from coal are still in the early stage of testing and development. DOE's program to develop the technology has emphasized (1) developing and

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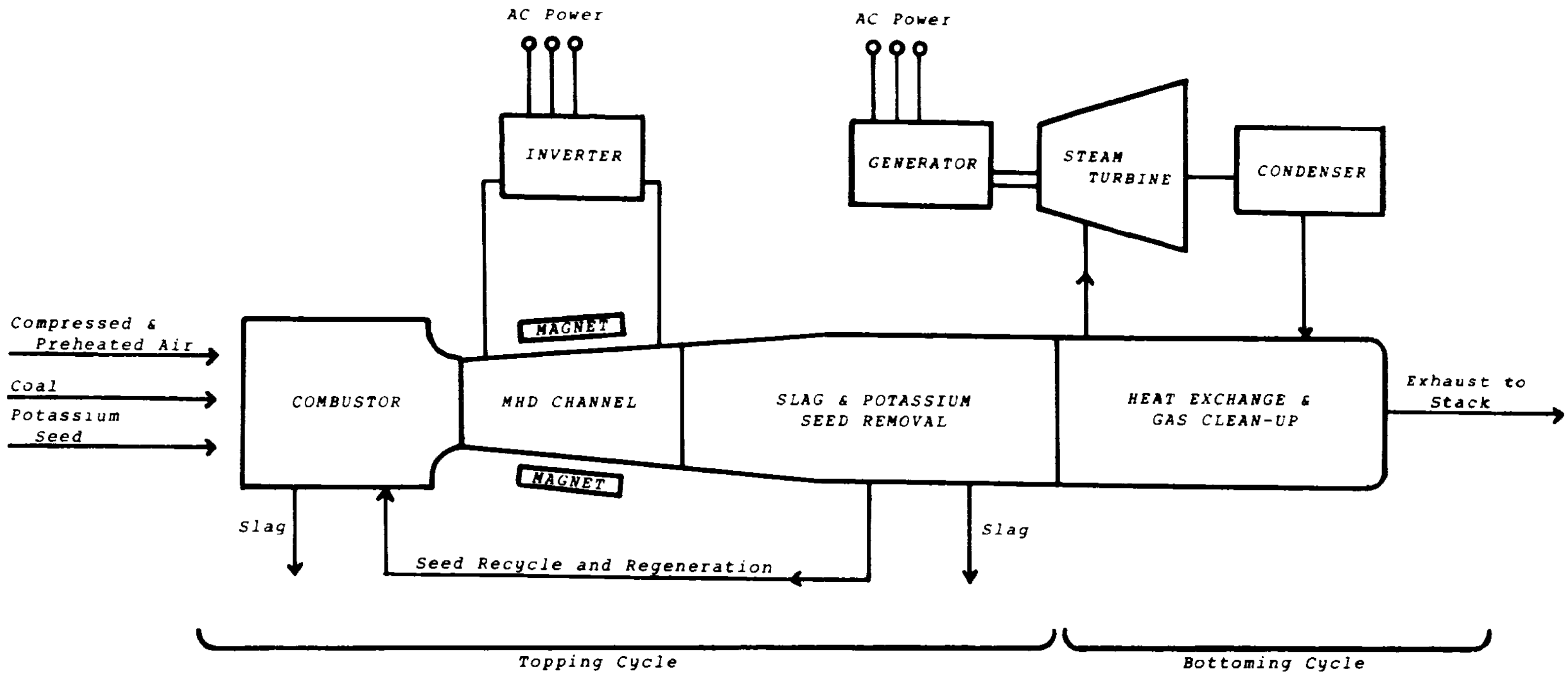
1/MHD is not limited to a specific fossil fuel. The U.S.S.R. and Japan are developing MHD systems which burn natural gas and oil. The United States has decided tó concentrate on developing MHD systems using coal as an MHD fuel. As discussed later in the report, using coal as an MHD fuel creates problems which do not exist for natural gas- or oil-fired systems. The United States feels, however, that coal is the most viable long-term fuel for MHD, and has based its MHD development program on coal.

2/Closed cycle MHD systems in contrast use coal or other fuel to heat a second gas--such as argon--which is then used to create electricity. Unlike open cycle MHD/steam systems which, after creating electricity and steam, exhaust the waste gas to the atmosphere, closed cycle systems recirculate the waste gas through the system.

FIGURE 1

DIAGRAM OF A COMBINED MHD/STEAM SYSTEM



Source: *Interim report of DOE's MHD Review Board.*

testing individual MHD components at several small, laboratory-size test facilities and (2) exchanging test equipment and information with Soviet MHD researchers. If DOE adheres to its schedule of facilities construction and MHD testing, a commercial MHD/steam powerplant burning coal will not be operating until the late 1990s--almost 20 years away.

The U.S. MHD program

Until recently, the United States MHD program had changed relatively little. In 1976, DOE's predecessor, the Energy Research and Development Administration, 1/ followed a three-phase program for developing MHD: (1) develop and test MHD components at multiple MHD test facilities; (2) scale up and test components at a medium-size MHD/steam pilot plant; and (3) operate a commercial-scale, several-hundred-megawatt 2/ MHD demonstration plant.

DOE is now about midway into the program's first phase. MHD components developed and tested at universities, national laboratories, and private contractors' laboratories will be tested at three test facilities. These facilities are:

--The 50-thermal-megawatt Component Development and Integration Facility (CDIF) in Butte, Montana. 3/

1/These functions were transferred from the Energy Research and Development Administration to DOE on Oct. 1, 1977.

2/A megawatt, equal to 1 million watts, is a unit of power. An electrical megawatt-hour, the amount of electrical energy generated by a facility in 1 hour, is equal to 3.41 million British thermal units of energy.

3/DOE rates MHD test facilities according to their capacity to generate heat (measured in thermal megawatts) rather than by a facility's electrical-megawatts capacity. The electrical energy generated from a thermal megawatt depends on a facility's efficiency. When operating at its original design capacity, for example, the Component Development and Integration Facility would generate only about 5 electrical megawatts. In comparison, commercial powerplants generate from about 20 to 1,400 electrical megawatts. According to DOE's 1977 Inventory of Powerplants in the United States, about three-fourths of the powerplant units scheduled for construction during the 1980s and early 1990s will be 750 electrical megawatts or smaller.

The facility will test the durability and efficiency of specific MHD components--those components associated with generating electrical power--by testing various combinations of new equipment for several hundreds of hours. For example, DOE has designed the facility with (1) two test areas to facilitate preparation of tests in one area while other tests are being prepared or test results analyzed and (2) capacity to store and annually dispose of waste generated by 500 hours of testing. Because of the type of components tested, and the duration of these tests, DOE intends that the facility will provide most of the information to design the planned MHD pilot plant. Thus, it is a "key" facility for the program.

--The 20-thermal-megawatt Coal-Fired Flow Facility in Tullahoma, Tennessee. This facility will test the efficiency, durability, and environmental emissions of one design of a MHD/steam system, and components of a second alternative system. Results of tests at this facility will be used in part to determine the need for further testing of competing MHD designs at the CDIF.

--The 250-thermal-megawatt Arnold Engineering Development Center, also in Tullahoma, Tennessee. Like the CDIF, this facility will only test specific MHD components--those which generate electric power--but at a scale about 10 times larger than the CDIF. However, this center is designed to test medium-size MHD systems and MHD components for intervals of tens of seconds, compared to the CDIF's hundreds of hours' annual testing capacity.

On December 11, 1979, DOE's Acting Assistant Secretary for Fossil Energy announced a new, two-phased MHD program to the Senate Committee on Energy and Natural Resources. The new program would eliminate the necessity for the program's third phase, commercial-scale demonstration plant by doubling the sizes of two facilities: (1) the phase 1 CDIF from 50 to 100 thermal megawatts, after about 3 years of testing at the 50-thermal-megawatt level and (2) the phase 2 pilot plant from 250 to 500 thermal megawatts. According to DOE, the newly accelerated program will not alter the functions of facilities and schedules originally planned for the program's first two phases.

DOE planned that construction would be completed and testing would begin at the phase 1 Arnold Engineering

Development Center and Coal-Fired Flow Facility by March 1979. As discussed in chapter 3 of this report, DOE has experienced delays starting tests at each facility. Testing started at the Arnold Engineering Development Center in July 1979 and is scheduled to start at the Coal-Fired Flow Facility in January 1980. Start of testing at the CDIF has been delayed from October 1979 to October 1980.

The near-term focus of DOE's MHD program is construction and operation of a 500-thermal-megawatt Engineering Test Facility--the program's MHD pilot plant. 1/ The facility will test a complete MHD/steam power system capable of producing about 10 times the MHD electrical power of the CDIF for 1,000 to 2,000 hours. If successful, DOE believes commercialization of the technology can be achieved without the construction of a demonstration plant. DOE is currently evaluating alternative designs for the pilot plant and plans construction to start during fiscal year 1986.

If DOE had continued with its plan to construct and operate a several-hundred-electrical-megawatt commercial-scale demonstration plant, design of the facility was scheduled to begin during the late 1980s, with construction beginning about 4 years later, and operations beginning during the late 1990s.

Prior to fiscal year 1980, DOE estimates the Federal Government will have spent about $273 million for development and construction of MHD test facilities and testing of MHD components. DOE estimates the total cost of the two-phased MHD program will be about $2.0 billion. DOE estimates a three-phased MHD program would have cost about $2.9 billion.

The U.S.S.R. MHD program

The Soviet Union--the main supporter of MHD research outside the United States--has taken a different approach to MHD development. 2/ Where the United States has emphasized gradual development of MHD systems using coal as a fuel, the Soviet Union has emphasized construction of large MHD and steam powerplants which burn natural gas. Because of this different approach and use of a different MHD fuel, the Soviets have already constructed and operated

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1/Throughout this report, we will use the terms Engineering Test Facility and MHD pilot plant interchangeably.

2/Japan, Poland, and the Netherlands also support various MHD research and development activities.

MHD facilities larger than those built by the United States--the U.S.S.R. operates (1) a 4-thermal-megawatt MHD test facility, (2) a 30-thermal-megawatt test facility, and (3) a 250-thermal-megawatt MHD/steam pilot plant. The Soviet Union also plans to start construction of a commercial-size (500 electrical megawatt) MHD/steam plant during 1984 which will burn natural gas.

The Soviets' long range MHD program plan includes the development of coal-burning MHD systems. They expect to introduce MHD powerplants into industry by stages, starting with the less complex facilities which burn natural gas. Coal burning MHD systems will be commercially introduced into industry as studies and operating experience with natural gas-fired systems accumulate. 1/

The United States and the Soviet Union have participated in each other's MHD program. Through an international cooperative agreement, the United States has built and loaned a first-of-its-kind MHD magnet for testing at a Soviet facility--American and Soviet scientists participated in these and other tests of MHD components. Similarly, Soviet MHD equipment has been tested at American MHD facilities and research groups from both countries have jointly sponsored international MHD symposiums. The cost of this international MHD program to the United States is relatively small compared to the annual cost of DOE's MHD program; the United States pays only for the costs of testing Soviet equipment at the smaller American facilities and for the manufacture of equipment for testing at Soviet facilities. For example, DOE has requested $1.5 million, or about 2 percent of the fiscal year 1980 MHD budget request, to continue exchanging MHD test information with the Soviet Union during fiscal year 1980. However, according to State Department and DOE officials, the status of these exchanges is uncertain in view of recent changes in U.S.-Soviet relationships.

Comparison of U.S. and U.S.S.R. MHD programs

It is difficult to compare the U.S. and U.S.S.R. MHD programs. Because the Soviet Union is already preparing to build a commercial demonstration plant, that country is in one sense ahead of the U.S. timetable for MHD development.

1/Open-Cycle Magnetohydrodynamic Electrical Power Generation eds. M. Petrick and B. YA. Shumyatsky, Argonne, Ill. 1978.

However, one reason for the advanced phase of the Soviet Union's program is that country's initial choice of natural gas as an MHD fuel. Natural gas is a cleaner fuel than coal and, when burned at MHD's high temperatures, produces fewer wastes and small mineral particles to corrode or foul MHD equipment. New materials and equipment have to be developed for MHD systems using coal which do not have to be developed for systems using natural gas. Comparison of the two countries' programs is also difficult because the Soviet Union's current expenditures for MHD research projects and construction of MHD test facilities are not known.

The two countries' approaches to MHD development reflect a basic difference in technology development philosophies. The United States has adopted a conservative "building block" approach of gradually increasing the size of MHD test facilities and using results of tests at the smaller facility to design larger facilities. This approach is used by the United States to develop other energy technologies and minimizes the risks of technology development. The Soviet Union's approach, on the other hand, can be described as building a large plant based on results at relatively small facilities and accepting the risk that costly changes may have to be made to the plant to make the effort technically successful. For example, the Soviet Union's 250-thermal-megawatt MHD pilot plant was built based on results of a 4-thermal-megawatt test facility.

Compared to the Soviet Union's program, the United States' revised two-phase MHD program can still be described as a relatively conservative "building block" approach. Given a United States objective of accelerating MHD by doubling the size of the proposed pilot plant, the United States could have decided to design a 500-thermal-megawatt facility based on results from the current 50-thermal-megawatt CDIF. This approach would have meant designing a pilot plant 10 times larger than the CDIF. However, the United States decided to add another step in the MHD facilities' "building block" sequence and double the CDIF test capability from 50 to 100 thermal megawatts. By doubling the size of the CDIF after about 3 years of testing at the 50-megawatt level, the United States' two-phase MHD program maintains the 5 to 1 ratio between pilot plant and CDIF which was the basis of the earlier three-phase program.

STATUS OF MHD TECHNOLOGY

Recent advances in development of MHD-related equipment are encouraging indicators of the technology's progress. Construction and operation of the new magnet being used in the Soviet MHD facility confirmed that the powerful, highly efficient type of magnet needed by a MHD/steam system can be designed and built. Also, a 500-hour test of electrical equipment in a DOE contractor laboratory facility suggests that special MHD materials can withstand the corrosive effects of coal combustion gases for 1,000 to 2,000 hours. Three years ago the best tests of this electrical equipment lasted 100 hours. Yet despite these advances, many substantial technical questions remain and must be answered before MHD can be considered an economic and technically viable technology.

For example, a new type of combustor needs to be developed if coal is to be used as an MHD fuel. An MHD coal combustor used by a utility or industry must operate for about the same amount of time per year as a conventional combustor, but at a significantly higher temperature. According to U.S. and U.S.S.R. MHD researchers, the MHD combustor's temperature, intensity, and efficency requirements are more characteristic of a rocket engine than a conventional combustor. In addition, the requirements to receive potassium or other seed material during combustion and to produce a gas with specific electrical characteristics is unique to MHD combustors. 1/ Problems related to combustor design include minimizing heat loss, electrically isolating the combustor from other powerplant equipment, and developing methods of economically rejecting coal slag or waste particles during coal combustion. Scale-up of alternative combustor designs from laboratory-size facilities could also be a problem.

Design of an efficient and durable MHD channel--the part of the MHD system which collects electricity from the moving, electrically charged gas--also faces technical problems. Electrical equipment lining the inside walls of the channel must withstand the stress of MHD's high temperatures and the corrosion of coal slag particles for 3,000 to 10,000 hours. Durability of the electrical equipment, efficiency-threatening electrical interference with the channel, and energy losses in large-scale MHD generators are problems which have yet to be solved. Also, most of the experience obtained to date has been with a coal-oil mixture or other fuel besides coal. The effects of coupling a larger-than-laboratory coal-fired MHD combustor to an MHD channel will not be identified until after the first coal-fired combustor is installed and tested in the Component Development and Integration Facility during fiscal year 1982.

1/Open-Cycle Magnetohydrodynamic Electrical Power Generation edj M. Petrick and B. YA. Shumyatsky, Argonne, Ill. 1978.

Development of other MHD components faces similar durability and scale-up problems. The equipment which preheats air supplied to the combustor must operate at a temperature higher than existing air heaters and, depending on how they are coupled to the system, withstand the corrosion of coal slag and potassium particles. Economic operation of an MHD/steam system requires equipment to separate, recover, and reprocess 85 percent to 95 percent of the potassium used by an MHD system. Designs of equipment used for similar purposes by industry are being evaluated, but have not been designed for a larger-than-laboratory MHD system. Also, although the design principles for a pilot-plant MHD magnet have been confirmed, larger magnets will have to be designed for commercial-size MHD/steam powerplants. Manufacturing techniques for producing these larger magnets may ultimately have to be refined if they are to be mass produced for utilities and industries.

Two questions are fundamental to the development of a coal-fired MHD/steam system: (1) whether the waste particles or slag generated by coal combustion should be removed from the system before or after potassium particles are added and the MHD gas moves through the system and (2) what trade-offs in design of individual MHD components must be made to maximize the efficiency and minimize operating costs of the system. DOE does not plan to resolve the first question until sometime during fiscal year 1983--after tests at the Coal-Fired Flow Facility and the CDIF. The second question can be answered only after operation of a complete MHD/steam system. The MHD pilot plant is now slated to include the first commercial-like MHD/steam test system burning coal.

MHD'S POTENTIAL FROM THE USER PERSPECTIVE

Electric utility companies will be the major users of MHD, once the technology is developed. The aluminum, chlorine, and other industries which heavily depend on electricity to manufacture their products are, however, other potential users of MHD. Based on studies and tests to date, MHD may be more economical and environmentally acceptable than conventional and most advanced coal-fired electric power systems. However, because of the technical questions which remain, most potential MHD users consider MHD a long-range technology.

MHD market potential

Two studies have compared MHD's projected efficiency and environmental performance with other generating systems which might be used by utilities. 1/ Both studies assumed MHD technology can be developed--a major assumption considering the early status of MHD development. DOE has not adequately assessed MHD's industrial potential--although the aluminum and other electricity-dependent industries consume about 6 to 8 percent of the Nation's electricity supplies. Considering the uncertainties facing MHD and the studies available, only a rough assessment of the technology's total market potential can be made.

The two studies which assessed MHD's potential in the utility market concluded that, based on scientific principles and test experience to date, MHD could become a major electric generating technology. The 1977 Energy Conversion Alternative Study projected that an MHD/steam powerplant may (1) be more efficient than either conventional coal-fired steam powerplants equipped with scrubbers or powerplants using atmospheric fluidized-bed boilers, (2) be as efficient as two other advanced electric technologies--combined gas and steam turbines and combined coal gasifier-fuel cell systems, 2/ and (3) meet January 1978 proposed Environmental Protection Agency sulfur dioxide and nitrogen oxide pollution standards. Specifically, the study estimated a 2,000 electrical megawatt MHD/steam powerplant would be about 48 percent efficient and generate electricity at a cost of about 3.2 cents per kilowatt-hour. Powerplants using a combined gas and steam turbine system or a gasifier-fuel cell combination were estimated to be about 47 and 50 percent efficient, respectively, while powerplants with an atmospheric fluidized-bed boiler would be 36 percent

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1/Energy Conversion Alternative Study, United States National Aeronautics and Space Administration, Sept. 1977, and Comparative Study of Advanced Cycle Systems, Electric Power Research Institute, Feb. 1978.

2/An atmospheric fluidized-bed boiler burns coal in a limestone and air mixture to generate a low-sulfur coal gas for a powerplant's steam turbines. Plants using advance gas and steam turbines would operate high-temperature gas turbines as a topping cycle and steam turbines as the bottoming cycle. Plants using a gasifier-fuel cell combination would use the battery-like fuel cell to chemically generate electricity from synthetic coal gases.

efficient. 1/ The Electric Power Research Institute (EPRI) projected that, based on these characteristics, MHD could be the technology chosen for about 45 percent of the new powerplants built between 2005 and 2025.

Information about MHD's environmental performance is limited to results of studies, such as the two studies discussed above, and results of tests at several small facilities. MHD's major environmental and health and safety questions relate to (1) the technology's emissions of sulfur dioxide, nitrogen oxides, and small particles of potassium and other chemicals and (2) the effect of MHD's strong magnetic fields on workers and the general public. Experimental results tend to confirm projections by the Energy Conversion Alternative Study and other studies that, with appropriately designed combustors, potassium recovery systems and other components, MHD systems can meet air quality standards. However, according to DOE's May 1979 MHD Environmental Development Plan, the effects of intense magnetic fields on humans are not completely understood. The health effects of MHD's magnetic field and the technology's emissions at larger-than-laboratory and pilot facilities need to be evaluated to better assess the environmental acceptability of commercial-like MHD systems.

Numerous uncertainties, in addition to environmental considerations, however, affect the potential of MHD and other coal-burning electric generating technologies. For example, the demand for new coal-burning electric powerplants after 2000 will depend, among other things, on the overall growth in the Nation's electricity demand, the price and availability of fossil fuels, the role of nuclear-generated electric power, and the remaining useful life of existing powerplants. The demand for a specific technology, such as MHD, depends on how well research and development can overcome technical, economic, and other barriers in relation to competing energy technologies.

Utility and industry views on MHD's potential

Electric utilities and industry are for the most part interested but cautious about MHD. Electric utilities generally do not have large technology research and development staffs and do not become directly involved in

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1/The study estimated conventional powerplants equipped with scrubbers operate at about 32-percent efficiency and cost 4.0 cents per kilowatt-hour to construct and operate.

technology development activities. Major utilities which have become involved with MHD include American Electric Power Company, a northeast utility; Southern California Edison Company; and the Tennessee Valley Autohrity (TVA); who each have entered or are about to enter into small contracts with DOE or DOE contractors. EPRI--the research arm of the utility industry-is the only other major utility-oriented organization supporting MHD research within the United States. During fiscal year 1979 EPRI spent about $1 million for MHD research and development.

TVA--the Nation's largest producer of electricity and largest utility consumer of coal--does not have definite plans for testing MHD during fiscal years 1980 to 1984. In a June 1979 letter, TVA's Chairman informed us the utility had recently decided to focus its limited staff and funding resources on coal-fired electric technologies and other energy options which can be in commercial operation during the early to mid-1990s. Because TVA considers MHD to be several years farther from commercial operation than conventional coal plants with either advanced environmental controls or atmospheric fluidized-bed boilers, TVA's role in MHD development during the next 5 years will be limited to (1) technical monitoring of MHD's progress and (2) a few selected activities in which TVA input is considered vital to the DOE and EPRI programs.

EPRI and officials of the 16 major utilities we contacted throughout the country generally considered MHD one of several long-range electric technologies. Several utility representatives expressed reservations about the complex technology required for the MHD process. These officials stated that they considered other technologies--such as combined-cycle gas and steam turbines--serious rivals for MHD's portion of the utility market.

Officials of the largest energy-consuming industries--paper, glass, steel, aluminum manufacturing, and chemical processing--were generally interested in MHD's technical status, but knew little about the technology. Industry seems more interested in near-term, low-risk technology such as fluidized-bed boilers than in such long-range, high-risk technologies as MHD. One company--Reynolds Metals Company, a major manufacturer of aluminum--was, however, actively involved in MHD research and considering building an MHD electric generating system at one of its manufacturing plants. The company operates a small MHD test facility which was built without Government funds, and holds patents on alternative designs for MHD electrical equipment. Other aluminum companies and representatives of two chlorine industry companies--which also depend extensively on electricity to manufacture their products--were interested in MHD but were not knowledgeable about the technology because it was considered too far into the future for the company's needs.

CHAPTER 3

PROBLEMS AND ISSUES FACING DOE'S CURRENT MHD TEST PROGRAM

DOE plans that test results from the three major MHD facilities discussed in the last chapter will be the basis for design of the MHD pilot plant--the focus of the program's second phase. DOE, however, has experienced delays in the starting of tests at each of these three facilities and, as part of a review of the total program, is reexamining its test plans. This chapter discusses the current status of DOE's MHD test activities, the potential impact of delays on the design of an MHD pilot plant, and alternatives for accelerating or maintaining DOE's pilot plant schedule.

DELAYS AT THREE MAJOR MHD TEST FACILITIES

Fiscal year 1979 was supposed to be a milestone for DOE's MHD program. DOE planned that, during this year, construction of two new MHD facilities--the Arnold Engineering Development Center and the Coal-Fired Flow Facility--was to be completed and testing could begin. DOE's fiscal year 1979 budget presentation to the Congress set the start of testing at the third new facility--the Component Development and Integration Facility--as sometime during fiscal year 1980. DOE's internal schedule, however, called for construction of this facility to be completed during fiscal year 1979 and testing to start at the beginning of fiscal year 1980.

Each of the facilities has experienced delays in construction, delivery, and checkout of test equipment, which has forced DOE to miss its internal working schedules. DOE has experienced 2- to 9-month delays with delivery and checkout of MHD test equipment at the Arnold Engineering Development Center and the Coal-Fired Flow Facility. Testing at the Arnold Center was delayed from May 1979 to July 1979 because DOE contractors had to recheck installation of a first-of-a-kind magnet after an electrical problem developed. The Coal-Fired Flow Facility has experienced a 9-month delay because of delays in construction and in delivery of an MHD combustor. DOE now plans testing at this facility to begin during January 1980 rather than the original March 1979 date.

Start of testing at the third facility, the CDIF, is delayed 1 year because of (1) construction modifications necessary to accommodate test equipment supplied by different contractors and (2) an 8-month delay in the delivery of an

MHD magnet. DOE now plans to start testing at the facility during October 1980.

The Government's schedule for developing MHD depends directly on the timely completion of tests at these three larger-than-laboratory test facilities. DOE plans to request congressional approval for design and construction of an MHD pilot plant 1-1/2 years before it commits funds to design that facility. Specifically, DOE plans to decide whether to proceed with pilot plant design during the middle of fiscal year 1981, as it prepares the Department's fiscal year 1983 budget request. Fiscal year 1983 is the target date for DOE issuing a request for proposals to design the facility and fiscal year 1984 is the date DOE plans to commit funds for preliminary design. DOE's March 1979 draft MHD management plan defines a sequence of tests and technical decisions to be made in order to meet this schedule. The schedule, however, is tenuous--DOE's March 1979 plan states that DOE will decide to proceed with pilot plant design only when adequate engineering and design data are available. Thus, DOE's schedule for design of an MHD pilot plant will depend on when tests at the three larger-than-laboratory facilities and other MHD development activities give DOE management the confidence to (1) request congressional approval for facility design funds and (2) contract for preliminary facility design.

Starting tests at the key CDIF in October 1979 would have given DOE about 1-1/2 years to gather test information on the performance and durability of MHD components at the 50-thermal-megawatt level before it decided whether to request congressional approval of a 500-thermal-megawatt pilot plant. It would have also given DOE about 4 years of testing and modifications at the 50-thermal-megawatt level before committing pilot plant design funds. As discussed in the previous chapter, DOE plans that the CDIF will provide most of the design data for the pilot plant. The facility will test eight combinations of 50-megawatt test equipment, with each combination including a more sophisticated magnet, combustor, or other first-of-a-kind MHD component. Tests of the first combinations of equipment--originaly scheduled in fiscal year 1979 program documents for fiscal years 1980 and 1981--will (1) help DOE evaluate the effects of scale-up of existing designs from laboratory to a larger-than-laboratory facility and (2) establish a base of experimental data to understand and evaluate the performance of more advanced designs. The more advanced coal-burning MHD equipment to be tested during fiscal years 1982 and 1983 will better resemble the type of equipment to be used in DOE's pilot plant designs.

For these reasons, delays at the CDIF could delay design of the MHD pilot plant. If DOE adheres to its decision schedule for the 500-thermal-megawatt MHD pilot plant, the 1-year delay at the CDIF will mean less time to check components of the first test systems after equipment is installed, less time to test the performance of these initial systems, or both. Less time to check out the complex MHD equipment after installation may result in later delays in facility testing--such as the 2-month delay experienced at the Arnold Engineering Development Center. Less time to test components may in turn result in less test data for DOE decisions and pilot plant designs. Thus, DOE could be faced with a decision whether to (1) request approval for pilot plant design to maintain the program's schedule, in spite of insufficient testing, or (2) delay pilot plant design.

DOE's plans to double the size of the CDIF will not provide additional information for these initial pilot plant decisions. DOE plans to begin modifying the CDIF during 1982 to allow testing of the larger 100-thermal-megawatt equipment. However, DOE does not plan to start testing this larger equipment until about January 1984--about 3 months after DOE plans to begin preliminary pilot plant design. Thus, DOE will be making decisions whether to start preliminary design of a 500-thermal-megawatt pilot plant based mainly on results of tests at the 50-thermal-megawatt CDIF. DOE then plans to use results of the 100-thermal-megawatt CDIF tests after 1984 to modify pilot plant design before construction begins.

DOE REVIEW BOARD QUESTIONS TEST FACILITY'S DESIGN AND SCHEDULE

During September 1978 the Secretary of Energy requested the Director of DOE's Office of Energy Research to evaluate the status and funding of the MHD program. The intradepartmental MHD Review Board 1/ issued a January 1979 interim report which discussed the program's test plans and schedules. The board's final report was completed in July 1979 and submitted to DOE's Under Secretary and Assistant Secretary for Energy Technology for their review prior to its release.

1/The Review Board consisted of representatives from the Offices of Policy and Evaluation, Energy Technology, the Controller, and Energy Research.

The Review Board's interim report made several recommendations to (1) maintain unchanged the Department's funding and priority for MHD relative to other technologies, (2) improve MHD project and program management by either increasing DOE headquarters staff or by delegating responsibility to field units, and (3) establish additional test requirements, milestones, and decision points to gauge the progress of MHD test activities. The interim report also recommended that DOE's test plans at the three major MHD test facilities be reviewed and modified to provide the maximum information for design of a commercial-like MHD pilot plant. This last recommendation was based on concerns about (1) the design of the CDIF and (2) the program's plans for conducting and evaluating tests at this and other facilities.

Specifically, the Review Board's interim report commented on one of two possible limiting factors in the design of the CDIF. As discussed on page 7 of our report, the facility was designed large enough to accommodate two MHD test systems--theoretically to allow preparation of one test system while tests were being prepared for the other system. However, because a concrete wall or other heavy partition was not built between these two test systems, equipment cannot be installed and checked out in one test while the other system is operating. The Review Board's report noted that, because of this design problem, testing delays could occur and the facility would probably not be able to meet schedules currently established by the program.

A second limitation in the design of the facility could restrict DOE's flexibility to respond to future delays. DOE built artificial reservoirs or ponds to hold and dispose of the water used to cool equipment operated at the facility. The reservoirs, however, have a capacity large enough to hold water from only the equivalent of 500 hours of testing per year. 1/ Additional on-site storage capacity would have to be built, or agreement reached for transportation and off-site disposal of cooling water, if DOE decides to conduct more than 500 hours of testing per year at the facility.

Aside from the question of testing schedules and dates, the Review Board expressed concern with the type of test information DOE plans to obtain from its test facilities. Focusing on DOE's test plans for the CDIF and the Coal-Fired Flow Facility, the Review Board's interim report stated that

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1/500 hours is equivalent to about 3 months of 40-hours-a-week testing.

management of the activities seems to concentrate on meeting deadlines for starting and finishing tests, and not on the type of information needed to design a commercial-like MHD pilot plant. The report also noted that the CDIF does not have sufficiently advanced test measuring equipment to measure what was happening inside the MHD equipment during tests. The report stated that (1) the program should better define the operating requirements of a commercial MHD/steam plant and use these requirements to define test objectives for current facilities and (2) consider using more advanced test measurement equipment in current test facilities.

MHD program officials are implementing several of the Review Board's recommendations. In a March 7, 1979, memorandum to the Acting Assistant Secretary for Energy Technology, DOE's Program Director for Fossil Energy and MHD Division Director stated that (1) basic MHD program objectives are now being derived directly from commercial MHD systems requirements, (2) the program is giving increased attention to the type of test measuring equipment used at facilities, and (3) plans for the three larger-than-laboratory test facilities are continually reviewed by the program officials. However, the memorandum did not specially define the scope and timing of these reviews.

OPTIONS FOR MAINTAINING OR ACCELERATING MHD'S DEVELOPMENT SCHEDULE

One of the major questions facing DOE and the Congress concerning MHD is the technology's development schedule--can it be maintained, should it be accelerated, or should it be delayed? The question focuses on the relationship between testing at the three-larger-than-laboratory test facilities and the MHD pilot plant schedule. It reflects concerns by MHD supporters on the one hand that the technology is not being developed fast enough and, on the other hand, concerns by DOE's MHD Review Board that the test schedule is already too ambitious. The answer involves deciding how much test information DOE and the Congress should have before proceeding with design and testing of an MHD pilot plant.

DOE options for maintaining test schedules

DOE program officials indicated to us that, in their opinion, the schedule for testing at the three major MHD test facilities can be maintained. DOE's acting MHD Division Director agreed that the test schedule is optimistic, but did not believe it is overly optimistic. The program manager responsible for the CDIF agreed that the absence of a protective wall prevents simultaneous work of the facility's two test areas, but stated that the test schedule does not assume simultaneous use of the two test areas. Instead, he suggested that most of the facility's time during fiscal year 1980 will be spent disassembling or installing test equipment--rather than in conducting tests--and that on rare occasions will installation of one test system interfere with testing of the other system. Finally, DOE program officials expressed the opinion that the 1-year delay in starting CDIF tests will not cause DOE to miss its fiscal year 1981 and 1984 pilot plant decision dates. DOE's acting MHD Division Director informed us he has not ruled out combining some of the initial facility testing and/or overtime to compensate for time lost because of these delays.

Of these two options we believe overtime is the more attractive alternative. Combining tests at the facility by testing several new MHD components at the same time will make it more difficult for DOE to isolate the causes of changes in the performance of test equipment and thus may weaken the quality of experimental data. Until the first combinations of MHD equipment are installed and checked out, however, it is not possible to determine (1) the cumulative effects of delays at the CDIF and (2) whether the overtime option will be enough to maintain the program's test schedule. If overtime does not adequately compensate for CDIF delays, DOE should reexamine its pilot plant schedule.

Advantages and disadvantages of options for accelerating MHD development

Several options exist for accelerating DOE's development of the technology, including (1) modifying the CDIF, (2) using overtime at the facility in addition to the overtime to maintain test schedules, (3) modifying test plans at other major test facilities, (4) beginning pilot plant design earlier than fiscal year 1984, and (5) skipping design of an MHD pilot plant and proceeding directly to design and construction of a commercial demonstration facility. The advantages and disadvantages of these options, presented in table 1 (see p. 23), are summarized in the following paragraphs.

Modifying CDIF design and/or using overtime at the facility

Because the CDIF is the principal facility for testing coal-fired MHD systems, accelerating testing at this facility will have more of a near-term effect on the

TABLE 1

Assessment Of Options For Accelerating MHD Development

Option	Advantages	Disadvantages
Modifying the CDIF (by building a protective wall between test areas or adding a third test area)	Increased CDIF's long-term testing capability.	Construction might interfere with test activities already planned and may further delay test schedule. Also, DOE will need to expand on-site storage or arrange off-site disposal of spent cooling water if annual testing exceeds 500 hours.
Using overtime at the CDIF	Accelerate testing without interferring with tests currently planned.	Limited effect on DOE's pilot plant schedule. CDIF test schedule depends primarily on schedule for delivery and installation of MHD test components. Without accelerating component delivery schedules, overtime can only minimize delays in CDIF testing. Also, potential need to expand on-site storage or arrange off-site disposal of spent cooling water if annual testing exceeds 500 hours.
Modifying test plans at other major facilities	Increased testing at other facilities (such as the Arnold Engineering Development Center) will provide additional experience with medium-sized systems which would complement CDIF testing and may improve pilot plant design.	Limited effect on DOE's pilot plant schedule. DOE plans to begin pilot plant design after testing of coal-fired combustors at the CDIF. These tests cannot be done at other facilities.
Beginning pilot plant design earlier than fiscal year 1984	Accelerate pilot plant design by 1 to 2 years.	Increased risk of ineffective pilot plant design. Limited test data available for coal-fired MHD combustors, channels, and heat recovery systems.
Skipping pilot plant design and beginning design and construction of commercial demonstration plant (several hundred electric megawatt)	Accelerate commercial demonstration plant 10 years. Eliminate requirement for pilot plant design, construction, and operating funds.	Significantly increased risk of ineffective commercial demonstration plant. A complete coal-fired MHD/steam system has not been tested outside the laboratory. Low probability of utilities and industries sharing cost of demonstration facility.

program's schedule than other options discussed in this report. Without the capacity for simultaneous operation of the CDIF's two test areas, however, it is questionable whether testing at the facility can be accelerated without (1) modifying the CDIF's design by either building a protective wall between the existing test areas or by adding a third test area or (2) using overtime at the facility. Once design modifications are completed, simultaneous operation of the two test areas or addition of a third test area would allow DOE to conduct more tests in relatively less time. Compared to this potential advantage of modifying the CDIF design is the potential problem that, because construction is almost completed and components are beginning to be installed at the facility, construction of a protective wall may interfere with and further delay DOE's planned tests. Also, although building a third test area close to but separate from the existing test areas may interfere less with planned tests, a third test area could probably not be completed and test equipment delivered in time to affect DOE's fiscal year 1981 decision whether to design the pilot plant.

Using overtime at the CDIF could accelerate testing at the facility without interfering with tests already planned. Unlike design modifications, overtime could also be implemented quickly enough to affect DOE's fiscal year 1981 pilot plant decision. If delivery and checkout of the more advanced coal-burning CDIF test components cannot be accelerated, however, the effect of overtime on accelerating the pilot plant schedule is limited to minimizing initial testing delays at the facility. In our opinion, it is doubtful whether component deliveries can be accelerated enough that overtime could be used to accelerate DOE's fiscal year 1981 pilot plant decision.

DOE's recent announcement to double the size of the CDIF will involve some changes in facility design. However, although DOE's schedule for the accelerated program does not reflect any changes in timeframe for the proposed pilot plant, a DOE official told us that DOE has not completed its evaluation of necessary design changes or the impact these changes will have on the facility test schedule. If additional testing delays occur because of doubling facility size, DOE may have to delay pilot plant design.

Modifying test plans at other facilities

Modifying test plans at other DOE larger-than-laboratory test facilities, such as the Arnold Engineering Development

Center and the Coal-Fired Flow Facility, would have an indirect effect on the program's schedule. For example, short-duration tests of alternative MHD channels at the medium-size Arnold Engineering Development Center facility would provide additional experience and data about the performance of medium-size MHD systems which could be used for pilot plant design. Additional tests at the Center's facility could also enhance DOE's confidence concerning MHD's technical feasibility and could contribute to DOE's fiscal year 1981 decision whether or how best to proceed with design of a pilot plant. However, DOE plans to start pilot plant design after testing of coal-fired combustors at the CDIF for 100 to 500 hours. The Arnold Center uses combustors which burn a hydrocarbon fuel other than coal, and the Coal-Fired Flow Facility can test CDIF-size combustors for only short periods. Because of these differences among facilities, testing at the Arnold Engineering Development Center facility and the Coal-Fired Flow Facility can complement but not substitute for tests of MHD combustors scheduled for the CDIF. Thus, unless DOE decides to begin pilot plant design before testing of the CDIF coal-fired combustors, expanding testing at other facilities will have a limited effect on DOE's pilot plant design schedule.

Beginning pilot plant design earlier than fiscal year 1984

A variation on the previous option for accelerating MHD's development schedule is that DOE could change its pilot plant schedule and begin preliminary design earlier than fiscal year 1984. By including a request for preliminary design funds as part of the Department's fiscal year 1981 or 1982 budget, if approved by the Congress, DOE could begin preliminary pilot plant design during fiscal year 1982 or 1983--before CDIF tests of coal-fired combustors are completed. This would involve a 1- to 2-year savings in DOE's current pilot plant schedule. However, a major disadvantage to this type of accelerated design schedule is the increased technical risk of an ineffective pilot plant design. Major technical uncertainties exist in the design of coal-fired combustors, channels, and other components of a pilot plant size MHD/steam facility. With the delays in starting tests at the CDIF and other facilities, an accelerated pilot plant design schedule allows DOE even less time to test and evaluate competing designs of these key components. The Government's experience with the Coalcon coal liquefaction demonstration facility--a project which failed partly because research and development problems with the technology were not ironed out before the facility was designed 1/--emphasizes the importance of minimizing technical uncertainties before design and construction of a major test facility.

Building a commercial demonstration facility based on existing data

Skipping pilot plant design and beginning design and construction of a several-hundred-electrical-megawatt MHD demonstration plant based on existing data could save as much as 10 years in MHD's development and commercialization. Offsetting the potential advantages to this alternative for accelerating the program are the technical and financial risks of inefficient and ineffective facility design. Because an MHD demonstration facility would be 2 to 5 times larger than a pilot facility, the technical risks of building a demonstration facility based on existing data are greater than the technical risks of building a pilot plant. Also, based on our contact with utilities and industries, it is doubtful whether utilities or industries would be willing to share the costs of constructing a $1 billion commercial demonstration plant based on results of tests at the three larger-than-laboratory facilities. The probability of cost overruns and schedule slippages, due to ineffective design and technology problems in design and construction of a commercial demonstration plant, appears, in our opinion, significantly higher than in the case of a "building block" approach to MHD development.

Our discussions with utilities indicate that these potential MHD users do not see the need for DOE to significantly accelerate MHD's development by designing and building an MHD commercial demonstration plant. The director of EPRI's advanced fossil power systems department commented that he does not see the urgency for building an MHD commercial demonstration plant, based on limited test data, considering other electric generating technologies now being developed. For example, atmospheric fluidized-bed boiler systems have operated successfully at pilot-plant-scale facilities and can be commercially demonstrated with comparatively less risk than MHD. In MHD's case, its potential for high operating efficiencies in a commercial plant must be weighed against the risks that the technical problems cannot economically be solved.

1/See our report, "First Federal Attempt to Demonstrate a Synthetic Energy Technology--A Failure," EMD-77-59, Aug. 17, 1977.

Representatives of the Tennessee Valley Authority, American Electric Power Company, and other utilities also emphasized the importance of DOE resolving MHD's technical problems before designing a demonstration or pilot plant facility.

CONCLUSIONS

In summary, there have been problems with delays and questions raised about testing at DOE's three major MHD facilities. DOE program officials believe that current test plans can be completed according to test schedules and will lead to design of a commercial-like MHD pilot plant. An ad hoc DOE Review Board, established to evaluate the program, reported that to achieve these objectives the MHD test plans should be modified.

Although MHD is a promising technology for efficient electric power generation, its potential cannot accurately be assessed until MHD systems burning coal are tested in larger-than-laboratory test facilities--such as the CDIF. We believe that DOE should strive to maintain the schedule for testing at the CDIF and other major MHD facilities.

Some options for accelerating MHD's development involve (1) modifying test plans at the CDIF or other facilities and (2) accelerating or skipping design and construction of an MHD pilot plant. Modifying test plans at the CDIF and/or other facilities to provide additional test data can improve the design of an MHD pilot plant and may increase DOE's confidence to start pilot plant design. However, the coal-burning MHD system being developed by DOE is first generation technology: coal-burning MHD systems require development and testing of MHD combustors and other components which are unlike components operating in the U.S.S.R. natural gas-fired facilities. In our opinion, DOE should not begin design of a 250- or 500-thermal-megawatt pilot plant until after completing tests of these first-of-a-kind coal-burning MHD systems at the CDIF. We believe it is unlikely DOE can sufficiently accelerate tests of the coal-burning MHD systems to accelerate effectively pilot plant design, because the CDIF schedule will be difficult to maintain even at the 50-thermal-megawatt level. Its plans to increase the CDIF size to 100 thermal megawatts could involve additional testing delays or problems which could affect the pilot plant's design and/or schedule.

Accelerating or skipping pilot plant design and construction would have a greater effect on MHD's long-term development than options for accelerating testing at the CDIF and other facilities. DOE could save 1 to 2 years in pilot plant design and construction if design were started before completing CDIF tests of coal-burning MHD equipment. DOE could save about 10 years by skipping an MHD pilot plant and designing a several-hundred-megawatt MHD commercial demonstration facility based on existing data. Test experience at the U.S.S.R. natural gas-fired MHD pilot plant reduces the risk of designing components such as the MHD magnet which are not affected by the use of coal as an MHD fuel. Technical problems and uncertainties exist, however, in the design of a combustor and other MHD components when coal is used as a fuel. In our opinion, because of the limited MHD test information available from larger-than-laboratory test facilities which use coal as a fuel and the technical and financial risks of designing MHD commercial demonstration facilities based on existing data, the risks associated with accelerating or skipping pilot plant design are high.

Considering the advantages and disadvantages of options presented in this report for accelerating the MHD program, we believe DOE should strive to maintain its current test schedule. Even maintaining DOE's test schedule may require adjustments such as the use of overtime in its current test program. Maintaining MHD's schedule, however, would help ensure that the MHD pilot plant design is based on adequate technical data and would minimize the likelihood of an ineffective outlay of Federal research and development funds.

DOE's recent changes in its MHD strategy could accelerate MHD's development if users are willing to accept the results from the pilot plant as demonstrating MHD's economic viability in the commercial market. However, increasing the size of the CDIF may delay testing of the CDIF coal-fired combustors, which could affect the pilot plant's design and/or schedule. We believe that a decision to double the size of the CDIF and in turn, the pilot plant, should only be made after a thorough analysis is made of the risks and benefits of this and other approaches for developing the technology.

CHAPTER 4

DOE SHOULD EVALUATE

ALTERNATIVE MHD PILOT PLANTS

Utilities' and industries' interest and support for a commercial MHD/steam powerplant will depend on the reliability, efficiency, and economics of MHD at a pilot plant facility and how close conditions at this pilot facility resemble commercial operating requirements. We believe DOE should fully evaluate alternative approaches for the MHD pilot plant. This would include an evaluation of a pilot plant associated with an operating industrial and/or utility facility as well as DOE's planned Government-owned-and-operated facility.

BACKGROUND

Prior to June 1978, DOE planned that the MHD pilot plant would be a "stand alone" test facility--a facility not associated with an operating electric powerplant. The pilot facility would test MHD and steam system components similar in design but smaller in size than those to be used in a commercial powerplant and would be capable of supplying a commercial product--electricity--to a utility's electric transmission lines. However, a utility would be involved with the facility only to the extent that it received electricity; the utility would not be directly involved in operating the pilot plant.

Since early 1978, DOE has received suggestions from Southern California Edison Company, the University of Tennessee, and Reynolds Metals Company for two alternatives to this DOE-planned MHD pilot plant: (1) a jointly owned and operated Government-utility facility and (2) a jointly owned and operated Government-industry facility. The primary objectives of these alternative pilot plants would be similar to the objectives of DOE's planned facility--to test the engineering, economic, and environmental performance of MHD/steam systems. Unlike DOE's proposed facility, however, the alternative pilot plants would consist of an MHD test facility combined with an operating utility or industrial plant. Cost of building and operating the joint facilities would be shared between DOE and the utility or industrial partners.

ADVANTAGES AND DISADVANTAGES OF ALTERNATIVE MHD PILOT PLANTS

DOE's decision which pilot plant approach to use should be based on analysis of (1) each approach's contribution to MHD's development and commercialization, (2) the time and cost of the approach, and (3) the Government's capability to control testing under the approach. The advantages and disadvantages of the Government, joint Government-utility, and joint Government-industry pilot plant approaches related to these three factors are presented in table 2. (See p. 31.)

A Government-owned-and-operated facility

A Government-owned-and-operated pilot plant has several advantages. The Government would not have to coordinate pilot plant design and construction schedules with utilities' or industries' construction plans and would not have to negotiate cost-sharing agreements with potential utility or industrial partners. Because the test facility would not be associated with an operating electric plant, the Government also would have complete control of testing schedules and implementation, and would not need to negotiate with a second organization to avoid potential conflicts between test and production schedules. Negotiations with potential utility or industry partners can require additional time and complicate administrative procedures for siting and construction of a test facility.

A disadvantage to the Government-owned-and-operated facility approach is that potential MHD users are not significantly involved in the program until design and construction of the program's commercial demonstration facility. User involvement in a Government-owned pilot plant would be limited to commenting on pilot plant design and test schedules. Increased user involvement in pilot plant construction and operation, on the other hand, may improve the likelihood that industries and/or utilities will share the cost of a commercial demonstration plant.

A joint Government-utility facility

The main advantage to a joint Government-utility pilot plant compared to a Government-owned-and-operated facility is that potential MHD users would be directly involved in design and operation of the joint facility.

TABLE 2

ADVANTAGES AND DISADVANTAGES OF ALTERNATIVE MHD PILOT PLANTS

Type of pilot plant	Advantages	Disadvantages
Government-owned-and operated test facility	Government would have greater control over project. DOE would determine timing of design and construction. There would be no need to coordinate with a second organization's (utility's or industry's) construction plans. DOE also would determine what tests are performed at facility, and when they are conducted.	User involvement in pilot plant is limited to providing advisory comments on design and test schedules.
Joint Government-utility-owned-and-operated test facility	Test facility would be associated with an operating powerplant. This could facilitate MHD's commercialization because (1) tests would be conducted in a real-life environment, (2) utilities would view results as being more realistic, and (3) utilities are the major potential users of MHD.	Since MHD "topping cycle" provides supplemental heat to an operating steam plant, MHD tests would have to be coordinated with the utility's electricity generating schedule. Government and utility would have to develop and implement procedures for minimizing potential scheduling conflicts.
	Government would pay for only part of the cost of building an MHD/steam powerplant. Although final Government costs must be negotiated, based on the Government paying only cost of constructing MHD "topping cycle", and interfaces and utility paying for construction of steam "bottoming cycle," DOE tentatively estimates cost savings at $24 to $36 million.	Potential for construction delays because (1) Government would have to coordinate construction plans with utility's construction and environmental analysis activities and (2) State regulatory agencies would have to review siting of a joint test facility/powerplant.
	Potential for 1 to 2 years' time savings in siting and construction of test facility if DOE decides to modify or retrofit an existing powerplant with MHD equipment because joint facility would be located at site already being used by utility. Also, potential for less environmental resistance to siting of test facility adjacent to an existing powerplant than to siting a test facility at a new location.	If DOE decides to retrofit an existing utility plant, rather than modify a new plant under construction, the modified facility could be less efficient than a new test facility.
Joint Government-industry test facility	Because a commercial industry MHD/steam system is smaller than commercial MHD/steam utility powerplant, an industrial MHD pilot plant could result in earlier industrial commercial use of MHD	Utilities' willingness to share the cost of an MHD commercial demonstration facility based on test results generated in an industrial pilot facility has not been determined.
		Potential for construction delays because Government would have to coordinate construction plans with industry's construction and environmental impact analysis activities, and State regulatory agencies' review activities.
		Government and industry would have to develop and implement procedures for minimizing potential conflicts in Government's test and industry's production schedules.

Direct involvement of MHD users with the technology is critical to obtaining the support of users and lending institutions necessary for commercial acceptance of MHD. Representatives of electric utility companies we contacted indicated that they would be more interested in results of an MHD facility operated jointly by a utility and Government than they would be in the results of a solely Government-operated facility. The utility representatives also indicated that DOE should be able to find several utilities interested in sharing the cost of a utility test facility--if the test facility is designed not to interfere with the utility system's capacity for generating electricity for its customers. Montana Power Company and Southern California Edison Company are two utilities which have proposed or are about to propose that one of their facilities be modified to accommodate MHD. TVA, on the other hand, has indicated that it is not interested in hosting an MHD pilot plant because of its higher priority for developing near-term energy technologies.

The Government-utility pilot plant is also attractive because of potential construction cost savings to DOE. For example, with the utility pilot plant, the Government would probably pay for only the cost of adding MHD components and making modifications to an existing or planned electric generating plant. A DOE contractor report which evaluates the technical feasibility and cost of a joint Government-utility facility estimates DOE can save $36 million by modifying a coal-fired powerplant and $24 million by modifying an oil-fired facility.

DOE program officials estimate that a joint Government-utility facility would require 1 to 2 years less time for siting and environmental studies than a Government-owned facility. A joint Government-utility pilot plant would be constructed by either (1) adding MHD components to an existing powerplant or (2) modifying the design of a powerplant yet to be constructed to include MHD equipment. Utilities we contacted agreed that DOE might be able to save 1 to 2 years siting a joint test facility--if DOE decided to modify an existing utility powerplant--because the host utility would have already acquired that site and obtained regulatory approval for the existing plant. They suggested that resistance to a utility adding capacity to or modifying an existing powerplant may be less from an environmental perspective than resistance to building a facility at a new site. On the other hand, if DOE decides to modify a powerplant yet to be constructed--such as one of the facilities Montana Power Company is considering for the MHD pilot plant--siting and regulatory review of the planned facility may take as long as siting of a Government-owned-and-operated test facility. The Montana legislature has appropriated $500,000 to evaluate these and other issues related to siting an MHD pilot plant in the State.

Compared with the advantages of a joint Government-utility facility are three potential disadvantages, from DOE's perspective, to the approach: (1) need to coordinate DOE siting and construction plans with utilities' construction plans, (2) potential for less Government control of testing at the facility, and (3) potential for less-than-optimal performance from experimental MHD equipment. For example, with the long lead times required for siting and construction of coal-burning electric powerplants, utilities are already planning construction of plants to be operational during the late 1980s. A Montana Power Company official indicated the Company is now considering potential sites for one of two powerplants it will propose to be modified to accommodate MHD equipment in order that the Company can complete siting reviews and construction by 1989. In our opinion, potential siting and construction delays can be minimized by the Government and a utility partner coordinating site selection, environmental studies, and approval of construction permits for a joint test facility.

The question of Government control of testing at a joint facility relates to the potential for conflict between the goals of a test facility and an operating powerplant. In a joint venture with an operating utility there is a chance that, because the utility owning part of the facility places higher priority on meeting the electrical demands of its customers, electricity production may at times take precedence and interfere with DOE's MHD test schedules. This disadvantage to a joint Government-utility faoility is in essence the converse of one of the advantages of a Government-owned facility. In our opinion, controls to minimize conflicts between testing and electricity production schedules at a joint facility can be identified and mutually agreed to during preliminary negotiations between DOE and a utility.

If DOE decides to modify an existing utility powerplant to accommodate MHD, the modified facility could also be less efficient than a new MHD test facility. Retrofitting any technology to an existing facility requires some engineering compromises, blending the new with the old, and may require expedient solutions which may degrade performance. In TVA's opinion, these expedient solutions may sufficiently detract from MHD's performance that the retrofit may not convince utilities to build a commercial-size MHD/steam plant. We agree with TVA that DOE needs to identify the efficiency and other performance characteristics which an MHD pilot facility needs to demonstrate to utilities, and that DOE should select the type of facility which best provides this information. Modifying a planned utility powerplant to accommodate MHD equipment and building that combined test facility-powerplant "from the ground up"--as opposed to modifying an existing utility plant--would minimize the types of problems TVA associates with a retrofit facility, and still involve users in design and operation of the facility.

A joint Government-industry facility

Advantages and disadvantages of a joint Government-industry MHD facility are similar to advantages and disadvantages of a joint Government-utility facility. A joint Government-industry facility would have the advantage of involving potential MHD users directly in MHD's development compared to a Government-owned and operated facility and the potential disadvantage of coordinating construction plans and of potential conflicts in tests and production schedules.

The difference between a joint Government-industry and a Government-utility MHD facility relates to the significance of involving electricity-intensive industries in the MHD program. An MHD pilot plant associated with an operating aluminum or other electricity-intensive manufacturing plant could result in earlier commercialization of MHD than a Government-utility pilot plant. For example, one of the major uncertainties in the development of utlility-oriented MHD systems is the effectiveness of large MHD components. In essence, researchers must verify that MHD components and materials which are effective at smaller laboratory-size facilities are also effective at larger, commercial-size facilities. The size of a commercial MHD/steam industrial system, however, is smaller than a commercial-size utility system. Reynolds Metals Company officials indicated that an MHD/steam system about the size of the planned 500-thermal-megawatt MHD pilot plant would be large enough to generate economically electricity and steam for an aluminum processing plant. Based on our contacts with utilities, it is not clear that utilities will be willing to build commercial MHD/steam systems based on the results of a 500-thermal-megawatt pilot plant. However, a 500-thermal-megawatt plant may suffice to demonstrate the commercial feasibility of the technology to large electricity-intensive industries.

A potential disadvantage of a Government-industry pilot facility is that electricity-intensive industries are the smaller of the two potential markets for MHD. Electric utilities generate about 90 percent of the electricity consumed in the Nation and will be the major users of MHD/steam systems. The MHD technology required for a 500-thermal-megawatt industry-oriented pilot plant, however, is similar to the technology required for a utility-oriented system. Thus, it is possible that the experience gained from operating an industrial MHD facility could be used to design a utility-oriented commercial MHD facility. Whether utilities would accept the test results generated by an industrial facility and, based on the results, share in the costs of utility-oriented facility should be determined.

DOE NEEDS TO EXAMINE THE INDUSTRIAL MHD ALTERNATIVE

DOE needs to further evaluate the industrial MHD alternative. DOE contracted for a 3-month study to evalute the feasibility of using MHD in an aluminum manufacturing plant. The contractor's October 1978 report concluded that because of the increasing demand for aluminum as an energy-saving lightweight material and the prospects of using MHD to cogenerate the electricity and heat needed to produce aluminum, a detailed engineering study of an industrial MHD pilot plant should be performed. DOE has not, however, evaluated the cost of building and operating such a facility, or the contribution an industrial test facility could make to the long-term development of MHD. DOE's acting MHD Division Director explained that DOE has not evaluated this alternative because (1) industry will not be the major users of MHD, (2) budget restraints have compelled DOE to focus MHD development towards the utility market, and (3) aluminum and other electricity-intensive industries will be able to adopt and use MHD systems developed for electric utilities.

We agree that electric utilities are the major potential users of MHD and that DOE should focus its long-term development of the technology towards this market. But the question whether DOE should build an industrial MHD pilot plant is more a question of strategy--could an industrial test facility improve MHD's chances for contributing to the Nation's energy supplies during the 1990s and also contribute to the long-term development of utility-oriented MHD systems? DOE needs to determine (1) what information electric utilities and electricity-intensive industries need from an MHD pilot facility, (2) how effective the three alternative pilot plant approaches are towards meeting these needs, and (3) the effect of each approach on MHD's potential contribution to electricity generation.

CONCLUSIONS

In summary, the joint Government-utility and Government-industry pilot plants offer attractive alternatives to a Government-owned-and-operated facility. Both alternatives would involve users directly in technology development and could facilitate MHD's commercialization. We believe that a disadvantage to both joint facility approaches of less Government control of testing at the facility can be minimized through negotiations and contractual agreements with a utility or industry partner. We also believe that given the complexity and long-term nature of MHD, the advantages of involving users in the pilot plant facilities outweigh the disadvantage in time and administrative burden that involving these users might entail. The critical question which DOE needs to resolve, however, before choosing between the alternatives is what information electric utilities and electricity-intensive industries need from an MHD pilot facility to advance MHD towards commercialization. To answer this question, DOE should more fully evaluate the contribution an industrial MHD pilot facility can make to the long-term development and commercialization of MHD.

CHAPTER 5

MHD USERS SHOULD BE MORE ACTIVELY INVOLVED IN DOE'S PROGRAM

Moving from laboratory testing to testing at large-scale facilities--the three test facilities now being constructed and the proposed MHD pilot plant--is an important turning point for MHD. These facilities and DOE's decision about alternative approaches for the MHD pilot plant will significantly influence MHD's chances for commercialization. Yet DOE does not have procedures to involve potential users, the final judges of MHD's commercial viability, in MHD's development. Active user involvement in the MHD program should be encouraged. To do this, however, DOE will have to develop new mechanisms and a new user-orientation to the program.

Chapter 4 discussed the potential advantages of DOE getting users involved in one phase of the MHD program: the operation of an MHD pilot plant. MHD users can also be involved in such other phases of the program as evaluation of test results from the current facilities, evaluation of alternative pilot plant approaches, and design of the MHD pilot plant. This chapter discusses the importance of DOE actively involving users throughout the MHD program and DOE's current limited approach to user involvement.

USER INVOLVEMENT CAN IMPROVE MHD'S CHANCES FOR COMMERCIAL ACCEPTANCE

Active user involvement in the development and demonstration of MHD is important for several reasons. Users can be a source and sounding board for institutional and market-related information affecting the relative demand for MHD. For example, electric utilities now seem to be building smaller, modular powerplants--adding new generating capacity by adding units or modules to existing powerplants. Electric utilities can alert DOE to such trends and suggest how these might affect MHD. Electric utilities and electricity-intensive industries can also provide DOE with a user perspective on design of an MHD pilot plant and DOE's general approach toward developing the technology. Last year, for example, EPRI canvassed some utilities and volunteered comments to DOE on several facets of the program. EPRI suggested that (1) although in general only new components or those components exposed to new work environments need be demonstrated in a plant, at some point the ability to start, control, and stop a complete plant must be shown, (2) alternative designs for MHD components may have to be investigated to meet utilities' maintenance requirements, and (3) a series of 150-, 200-, and 300-electrical-megawatt commercial demonstration facilities may be needed before DOE builds one rated at 400 to 500 electrical megawatts. Such user input can help focus the program on activities which answer users' needs about a technology and thus help reduce some of the uncertainties associated with demonstrating and commercializing MHD. As DOE's program moves towards testing at larger-than-laboratory and pilot plant facilities, such user input should become a permanent feature of DOE's program.

INVOLVEMENT OF POTENTIAL USERS SHOULD BE ENCOURAGED

DOE does not have procedures to encourage and incorporate user interest in the MHD program. MHD program officials have informally contacted EPRI officials for their comments and suggestions on the program. Except for this, DOE's basic approach to involve electric utilities and industry directly in the program has been to wait for these MHD users to come to DOE. The three utilities which have done so--American Electric Power Company, Southern California Edison Company, and the Tennessee Valley Authority (TVA)--are involved in small consulting or MHD research and development activities. Although these utility-initiated contacts have helped make MHD program management aware of specific utilities' concerns, more contacts are needed as DOE moves design construction and operation of a $372 million pilot plant.

DOE contacts with companies which manufacture electric generating equipment can also help make DOE aware of users' concerns and needs. DOE has contracted and should continue to contract with major suppliers of electric power systems for design and development of MHD components and facilities, and to solicit their comments and viewpoints on the program.

We believe that DOE should also do more to involve potential users directly in the program. DOE should involve EPRI, individual utilities, and electricity-dependent industries in the MHD program. EPRI can support utility-related MHD research and development activities, summarize MHD market-related information, identify utilities interested in working with DOE, and be a liaison with these utilities. DOE should also work with utilities and industry directly--to identify and address potential users' needs for information about MHD and to facilitate MHD's commercial acceptance.

A few potential users--even major utilities such as American Electric Power and TVA--cannot adequately reflect the needs of utilities throughout the country. These two utilities operate a specific mix of fossil fuel-, hydro-, and nuclear-powered electric plants to meet the environmental standards and electrical needs of their specific regions. Environmental standards differ throughout the country. For example, electric powerplants located near heavily populated, industrialized, wilderness, or park areas must meet environmental emissions standards different from standards for moderately populated rural or suburban areas. Availability of water to operate or cool new electric powerplants and the availability of low-moisture, easier-to-handle coal also differs widely in the various parts of the country. These differences can and should be considered as DOE develops MHD.

We discussed user involvement in DOE's MHD program with EPRI and officials of several major utilities. EPRI's director of fossil energy research and development programs stated that, in his opinion, increasing user involvement in DOE's MHD program is the most important improvement which could be made to the program. Officials of coal-consuming utilities--such as Pennsylvania Power and Light and Commonwealth Edison Company--indicated that utilities generally would be interested in providing DOE with advice and comment concerning MHD's development. In commenting on a draft of this report, the Chairman of TVA's Board of Directors suggested DOE consider establishing a national MHD coordinating group as was established for the development of fuel cells. TVA and DOE are preparing an interagency agreement to participate in a limited number of joint MHD research and design activities.

Because EPRI, utilities, and electricity-intensive industries can provide an important user perspective to MHD development, we believe DOE should take the initiative to involve these organizations more in the technology's development. One way to involve potential users is an annual survey sponsored by DOE to identify users' changing perspectives and concerns about MHD based on (1) technical progress made by MHD and other technologies and (2) changes in the electric utility market. Another method would be a series of regional meetings to discuss users' concerns, alternative designs for the MHD pilot plant, and results from the current MHD test facilities. Regardless of the approach, however, DOE needs to establish and emphasize a mechanism for involving a representative cross section of users in the program.

CHAPTER 6

CONCLUSIONS, RECOMMENDATIONS,

AND AGENCY COMMENTS

For fiscal year 1980, DOE has requested $662.7 million to develop and demonstrate technologies for converting the Nation's most abundant fossil resource--coal--into energy. MHD is just one of these technologies, which, even if DOE adheres to its pilot plant schedule, will not be demonstrated in a commercial-size electric powerplant until the 1990s. Should DOE continue to develop this long-term technology? Should DOE accelerate the MHD pilot plant so that the Nation can begin to commercially use the technology sooner? What improvements can DOE make to the MHD program to more effectively develop technology which will best meet MHD users' needs? These are the major MHD-related questions facing DOE and the Congress.

CONCLUSIONS

MHD is a promising but relatively unproven technology. It promises high operating efficiencies and low environmental emissions. Solutions to the many technical problems associated with using coal as an MHD fuel need to be tested and demonstrated. Based on studies available, MHD is sufficiently promising that DOE should continue developing it to a point where MHD's technical and economic potential can be more reliably assessed. The small-scale tests and few engineering studies of MHD and other technologies are only indicators of MHD's potential. On the other hand, DOE's tests at the three larger-than-laboratory MHD facilities will, if designed and implemented properly, provide DOE with information more closely resembling a commercial operating environment which DOE can use to better evaluate MHD's commercial potential. DOE should work with utilities and electricity-dependent industries to define the efficency, economics, and other technical characteristics which will make MHD systems commercially attractive and use results of the current test program to assess how well MHD systems meet these requirements.

As for accelerating technology development by accelerating tests at the three larger-than-laboratory test facilities, DOE's schedule for testing at these facilities is ambitious and delays have been experienced. In our opinion, DOE will have a difficult enough task maintaining the current test schedule.

The benefits from DOE accelerating MHD's development by accelerating or skipping design and construction of an MHD pilot plant must be weighed against the risks of technical failures and cost overruns due to premature plant design. Benefits from accelerating the pilot plant by beginning facility design based on existing test data include a 1- to 2-year saving in pilot plant design and construction. If this 1- to 2-year saving carries forward to design and construction of a commercial plant, accelerating pilot plant design could mean having MHD commercially available 1 to 2 years sooner. Similarly, the benefits from skipping pilot plant design and beginning design of a several-hundred-electrical-megawatt commercial demonstration facility based on existing data include the potential for having MHD commercially available 10 years earlier. These benefits would accrue, however, only if an accelerated pilot plant and/or commercial demonstration facility demonstrates MHD's competitive advantage and readiness for the commercial market. MHD is a first-of-a-kind technology which requires that new and complex components be developed and tested. Limited test data have been obtained on larger-than-laboratory coal-burning MHD systems, and technical uncertainties about design and performance of commercial MHD/steam systems remain. Because of the limited data and technical uncertainties, the risks of developing an ineffective pilot plant and/or commercial demonstration plant must be carefully weighed against the potential benefits from accelerating MHD's development.

We have not quantified the benefits and risks associated with accelerating and/or skipping pilot plant design and construction. Based on our review of the status of MHD technology using coal, and DOE's experience with the Coalcon coal liquefaction facility, in our opinion the technical risks of accelerating development are high.

DOE's recent announcement to double the size of the CDIF from 50 to 100 thermal-megawatts and in turn, double the size of the proposed pilot plant from 250 to 500 thermal megawatts will include some changes in design of the existing CDIF. DOE has not completed its evaluation of design changes or the impact these changes will have on the facility test schedule. Its plans to double the CDIF size could involve additional testing delays or problems which could affect the pilot plant's design and/or schedule.

In DOE's opinion, eliminating the need for a $1 billion Government-owned-and-operated commercial demonstration facility is a major potential benefit of the revised program. Based on our contacts with utilities, however, it is not clear that utilities will be willing to build commercial MHD/steam systems based on the results of a 500-thermal-megawatt pilot plant. Commercial-scale utility-oriented MHD/steam systems may be several times larger than the pilot plant DOE is planning to build. In view of the issues raised, we believe DOE should make a thorough analysis of the risks and benefits of this and other approaches to accelerating the technology.

Opportunities exist to improve the effectiveness of DOE's MHD program. Because DOE plans to use test results from the three new larger-than-laboratory test facilities as the basis for design of a pilot plant, testing delays at these facilities could affect the quality of information available for pilot plant design. The Department has already experienced from 2-month to 1-year delays in starting testing at the three facilities. Further delays are possible because of design limitations at the CDIF, and DOE's revised plans to double the CDIF's testing capabilities.

We believe the Department should strive to maintain its schedules for facility testing and pilot plant design. DOE should evaluate the (1) status of component delivery and testing and (2) costs and benefits of overtime, modifying facility design and other options, early enough that DOE can minimize delays in the test schedule. If more delays occur, however, and these options cannot provide sufficient test results to effectively design a pilot plant, the Department should reexamine the pilot plant schedule.

DOE should also evaluate the advantages and disadvantages of a joint Government-industry MHD pilot plant and resolve the question of alternative pilot plants. DOE's selection of an approach of an MHD pilot plant should be made sufficiently early to allow DOE to maximize coordination with utilities', industries', and DOE's construction plans. The earlier the decision is made before fiscal year 1981 the less likely delays will occur in construction of a facility.

Finally, DOE should develop a mechanism to actively involve MHD users--electric utilities and electricity-intensive industries--in the MHD program. User input can help focus the program on developing a technology which meets users' needs and should become a permanent feature of the program. Users could be involved in DOE's evaluation of test results from the current facilities and selection of alternative pilot plant concepts, as well as in the design and operation of the program's MHD pilot plant.

RECOMMENDATIONS

To improve the effectiveness of the Department's MHD program, we recommend the Secretary require a report from the Department's Assistant Secretary for Fossil Energy before the fiscal year 1981 pilot plant design decision which includes an evaluation of

--the status of component delivery and testing at the three new test facilities,

--the advantages, disadvantages, and trade-offs of the use of overtime and other approaches to minimize delays in the pilot plant design schedule, and

--the advantages, disadvantages, and trade-offs of Government-owned-and-operated, joint Government-utility, and joint Government-industry MHD pilot plants.

We also recommend the Secretary establish a mechanism such as periodic regional users' meetings and surveys to actively involve electric utilities and electricity-intensive industries in the Department's program.

AGENCY COMMENTS

We sent copies of the draft report to DOE and TVA. Appropriate changes were made in the report to reflect their comments.

DOE comments

DOE agreed with the report's conclusions and recommendations and observations concerning the risks of accelerating MHD's development. (See app II.) DOE also discussed plans to accelerate MHD's development by doubling the size of the pilot plant. However, DOE has not completed its analysis of the risks and benefits of this decision. Therefore, it remains to be seen if this approach has merit.

TVA comments

TVA also agreed with the report's conclusions and expressed the opinions that (1) the adverse impact of slippage in the MHD program has been mitigated by developments in other coal-burning electric technologies, and (2) the incentive may not exist for industrial-size MHD systems because the smaller industrial systems might not be as efficient and cost effective. TVA also suggested the report expand and update its discussion of MHD's environmental considerations. The report's discussion of MHD's environmental performance has been revised accordingly.

UTILITY AND INDUSTRIAL

FIRMS CONTACTED

Alcoa
Pittsburgh, Pennsylvania

Allied Chemicals Corporation
Morristown, New Jersey

American Electric Power Service Company
New York, New York

Baltimore Gas and Electric Company
Baltimore, Maryland

Commonwealth Edison Company
Chicago, Illinois

Consolidated Edison Company of New York, Inc.
New York, New York

Dow Chemical Company
Washington, D.C.

E.I. DuPont de Nemours and Company
Wilmington, Delaware

Florida Power and Light Company
Miami, Florida

Gulf Oil Company
Pittsburgh, Pennsylvania

Houston Lighting and Power Company
Houston, Texas

Idaho Power Company
Boise, Idaho

International Paper Company
New York, New York

Kaiser Aluminum and Chemical Corporation
Oakland, California

Middle South Services Inc.
New Orleans, Louisiana

Mobay Chemicals
Pittsburgh, Pennsylvania

Montana Power Company
Butte, Montana

Pacific Gas and Electric Company
San Francisco, California

Pennsylvania Power and Light Company
Allentown, Pennsylvania

Pittsburgh Plate Glass Company
Pittsburgh, Pennsylvania

Reynolds Metal Company
Sheffield, Alabama

Southern California Edison Company
Rosemead, California

Southern Services Inc.
Birmingham, Alabama

Tennessee Valley Authority
Knoxville, Tennessee

Texas Utilities Company
Dallas, Texas

Tuscon Gas and Electric Company
Tuscon, Arizona

APPENDIX I

Union Electric Company
St. Louis, Missouri

United States Steel
Pittsburgh, Pennsylvania

Weyerhaeuser Company
Seattle, Washington

U.S. Department of Energy
Washington, D.C. 20585

JAN 3 1981

J. Dexter Peach, Director
Energy and Minerals Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Peach:

We appreciate the opportunity to review and comment on the GAO draft report entitled "Magnetohydrodynamics: A Promising Technology For Efficiently Generating Electricity From Coal." Our views with respect to the text of the report and recommendations contained therein are discussed below.

We fully agree with the report's observation that early commercial availability of magnetohydrodynamics (MHD) power will be achieved only if the "...pilot plant and/or commercial demonstration facility demonstrates MHD's competitive advantage and readiness for the commercial market." Program strategy has been revised precisely to ensure that end. As now proposed, the Engineering Test Facility (ETF) is a true commercial prototype of approximately 500 MW thermal input. Performance of this plant under commercial power generating conditions (following shake-down) would be expected to meet or surpass utility fuel and operating cost standards and availability criteria existing at that time. The current ETF would be expected to facilitate rapid commercialization of MHD power by the electric utility industry.

The report correctly stresses the increased risk engendered by an accelerated approach to commercial readiness. However, it should be pointed out that the revised ETF strategy takes this concern into account in three ways, namely:

a. Firm performance requirements, based realistically on utility standards, are being completed to qualify component and subsystem designs prior to ETF selection.

b. Key MHD generator qualification testing - i.e., verification that selected designs are capable of meeting commercially derived standards - will be conservatively scaled at about 1/5th ETF size.

c. The ETF conceptual design is being simplified in a manner to take fullest advantage of existing technology with no compromise of essential performance benefits or operating requirements of the basic MHD power cycle.

We believe that these three steps, taken together, offer a sound approach to a considerably earlier demonstration of commercial readiness than could be achieved through a 250 MW ETF as conceived in the original plan and as considered in the GAO study. Further, we believe that the new ETF strategy would probably reduce total costs to the Government without any significant increase in technical risk. We concur completely with the report's insistence that earlier demonstration of commercial readiness should not incur increased technical risk. We believe this is avoided in the new ETF strategy.

Further, a few words about how we propose to simplify the ETF. Performance analyses which we've been conducting over the past year, show a virtual stand-off between high temperature (2500°F) combustion air or low temperature (1100°F) combustion air with added oxygen (34%). Cost and risk considerations clearly favor the oxygen approach. This is because the low temperature air can be provided directly by capturing waste heat from the MHD plant while the high temperature air would need to be generated separately in special regenerative air heaters. Although there is a broad industrial base available for the development of such high temperature separate air heaters, they nonetheless introduce new conditions which would require considerable development time and money. Oxygen production capability, on the other hand, is well established industrially and could be installed at an ETF plant site on virtually a turnkey basis. Cost analyses indicate that adding extra oxygen to low temperature combustion air would not compromise the potential fuel economy advantages of MHD power generation.

We are in agreement with the report's conclusions and recommendations.

We appreciate your consideration of these comments in the preparation of the final report and will be pleased to provide any additional comments you may desire.

Additional comments have been provided to members of your staff.

Sincerely,

Jack E. Hobbs
Controller

TENNESSEE VALLEY AUTHORITY
KNOXVILLE, TENNESSEE 37902

OFFICE OF THE BOARD OF DIRECTORS

JANUARY 4 1980

Mr. J. Dexter Peach, Director
Energy and Minerals Division
United States General Accounting Office
Washington, DC 20548

Dear Mr. Peach:

Thank you for your November 16 letter asking us to review and comment on your draft report entitled "Magnetohydrodynamics: A Promising Technology for Efficiently Generating Electricity from Coal." We have noted and are complying with the limitations on the use of this report.

The following paragraphs present our overall impressions of the report and the national MHD program. Editorial and other specific changes which might improve the quality and accuracy of the report are given in the enclosure. One such point that should be mentioned here is the reference on pages 17 and 48 to a TVA-DOE interagency agreement. The agreement has not yet been signed, but documents are being prepared.

In general, we certainly agree with the main conclusions of the report; namely, (1) DOE should adhere as much as practical to its schedule for a pilot plant as the next major step after the Component Development and Integration Facility, (2) electric utilities and electricity dependent industries should be more actively involved in the program, and (3) an evaluation of the various pilot plant options should be made before a commitment is made. However, we are concerned about the report's strong emphasis on the delays experienced by the component development and testing program. We believe that the adverse impacts of slippages in the MHD program such as have occurred in the past are mitigated by developments in other coal-fueled electric generating technologies which will permit greater use of coal resources and the reduction in electric power growth rates.

We certainly support joint government and user cooperation in the MHD development program. In this regard, we suggest that consideration be given to forming a national MHD coordinating group such as was established for fuel cells. Further, we believe that emphasis should also be placed on the need for cooperation from potential designers and manufacturers of MHD equipment. While it would not be appropriate for them to serve on a program coordinating group, their input should be considered.

Regarding industrial MHD systems, it is important to recognize that they would probably be considerably smaller than the coal-based systems envisioned in the Energy Conversion Alternative Study (ECAS). Since the smaller systems probably would not be as efficient and cost effective, the key incentive for developing MHD may not exist for industrial-sized systems. We recommend that a detailed quantitative evaluation of these and perhaps other issues should be made before committing to major facilities in the MHD program.

The report gives only passing mention to environmental considerations, stating simply that MHD offers potentially low environmental emissions. We recommend that questions such as potential potassium sulfate emissions be addressed and that an updated environmental discussion be prepared to replace the ECAS reference to January 1978 proposed standards given on page 16.

We appreciate the opportunity of participating in the advance review of your report. Dr. Graham R. Siegel of our Energy Demonstrations and Technology Division (FTS 854-3941) will be happy to answer any questions you might have on our comments.

Sincerely,

David Freeman

S. David Freeman
Chairman

Enclosure

(306210)

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