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Frederick Hamilton Leich
The University of Montana

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MAGNETOHYDRODYNAMICS (MHD) AS A FUTURE POWER GENERATION METHOD IN THE STATE OF MONTANA

by

Frederick H. Leich

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CHAPTER I

INTRODUCTION

On September 23, 1970, the New York Daily News reported that "The Consolidated Edison Co., for the first time in its history, temporarily cut off power completely yesterday to 90,000 customers and reduced voltage three times, the last time at 7:05 p.m. It was the worst day of the power crisis and more of the same loomed as 90-plus (sic) humid weather was predicted for today."[1]

The power termination was not the result of an unexpected plant failure in New York, nor was it due to a transmission failure like the Eastern Blackout of 1965. Power was shut off because, for the first time in over 80 years, demand for electricity in New York City exceeded Consolidated Edison's ability to supply it. What occurred in New York City will occur again. Blackouts will occur not only in New York but in every major city and population center in the nation. Power blackouts will be an inconvenience of everyday living unless our society develops economical generation methods which deliver inexpensive electric power in the massive quantities forcasted for future needs.

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[1] Robert Carrol, "Heat's On & Con Ed Cuts Off 90,000 Homes," the New York Daily News, September 23, 1970, p. 5.

The problem of keeping up with expanding power demand is not the same as it was in the past. Power consumption is doubling every ten years.[2] In the next ten years our nation must duplicate a power generation capability which took over 80 years to develop.[3]

Moreover, increased power consumption is not the lone contributor to the power dilemma. Social demands for a healthier and more aesthetic environment impose new constraints on our ability to increase generating capacity economically.

A national power crisis appears imminent unless some corrective action is taken soon. Our nation possesses the expertise to avert a power crisis. Scientists have conceived more efficient power production and transmission methods which are less harmful to our environment. These new methods can produce power in volumes required to meet future demand. One such power generation method is Magnetohydrodynamics (MHD) and Montana is an ideal location for an MHD power generation industry.

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[2] Table 14 in Appendix I shows past power consumption from 1940 through 1969.

[3] Federal Power Commission, <u>FPC News Release No. 16323</u>, September 24, 1969.

Research Methodology

This study includes estimated cost data for MHD as well as known cost data for existing power production methods. Data was also researched to compare MHD environmental effects with those of other power generation methods.

The research methodology involved analyzing tests, special reports on MHD, power production cost data, transmission studies, periodical literature, hearings and conferences on MHD, statements, reports, power consumption data, power production forcasts, personal interviews and correspondence.

Summary of Findings

Nationwide demand for electrical energy is doubling every ten years. Parts of our nation have already suffered blackouts and brownouts. Power requirements for the Pacific Northwest and Central United States are expected to continue to reflect national trends. Differentials in usage between the Pacific Northwest and Central United States make a high voltage transmission intertie economically feasible. The State of Montana is strategically located between these two power demand centers and therefore could serve as an ideal power supply point. Montana possesses extensive coal resources to support a large scale coal fired power production industry.

United States scientists began developing an innovative power production technique called Magnetohydrodynamics (MHD) in the late 1950's. This new power production method shows promise of competing economically with existing power generation methods. In addition, MHD is thermodynamically more efficient than nuclear or conventional steam power plants. MHD is capable of producing bulk power in coal fired generating plants while producing less than ten percent of the pollutants produced in traditional coal fired plants. Higher MHD thermal efficiencies would reduce this form of pollution. A large MHD power production facility located in Montana would provide the following:

(1) A method for producing more power while substantially reducing environmental damage.

(2) More efficient use of coal in electrical energy production.

(3) A basis for industrial development in a state where a lagging job market is causing emigration of many young people.

(4) Greater efficiency in the use of existing generating capacity through a national power grid (intertie).

CHAPTER II

THE POWER CRISIS

The Growing Demand For Power

The rate of electrical energy consumption for the United States is doubling every ten years (Figure 1). This geometric expansion indicates that by 1990 there must be enough generating capacity to supply six trillion kilowatt-hours of electricity, 4.5 trillion kilowatt-hours over 1970 usage.[1] If the ratio of generating capacity to power consumption remains constant, there must be added to present plant investment by 1990 an additional generating capacity whose total wattage exceeds 1,250 million kilowatts (Figure 2).[2] This projected generating capacity represents an increase of over 900 million kilowatts from present capacity, costing over $100 billion.

Americans are constantly increasing their dependence on electric power. Per capita electric energy consumption increased steadily from 1357 KWH per year in 1940 to 7936

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[1] Federal Power Commission, F.P.C. News Release No. 16323, September 24, 1969, p. 5.

[2] U.S., Department of Commerce, Statistical Abstract of the United States, 1970, table 776, p. 507.

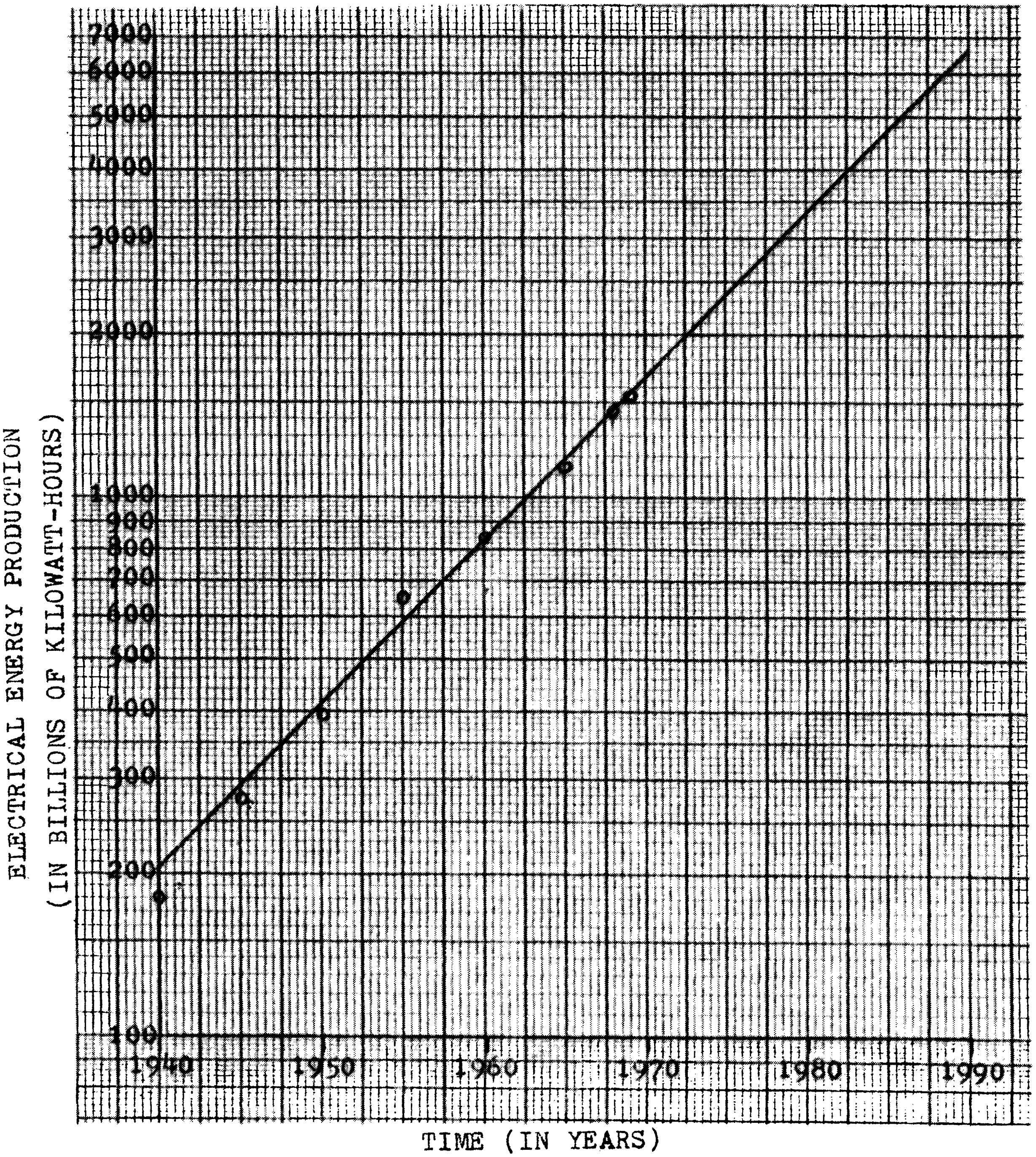

Fig. 1.--Free hand graph showing electrical energy production versus time projected to 1990.

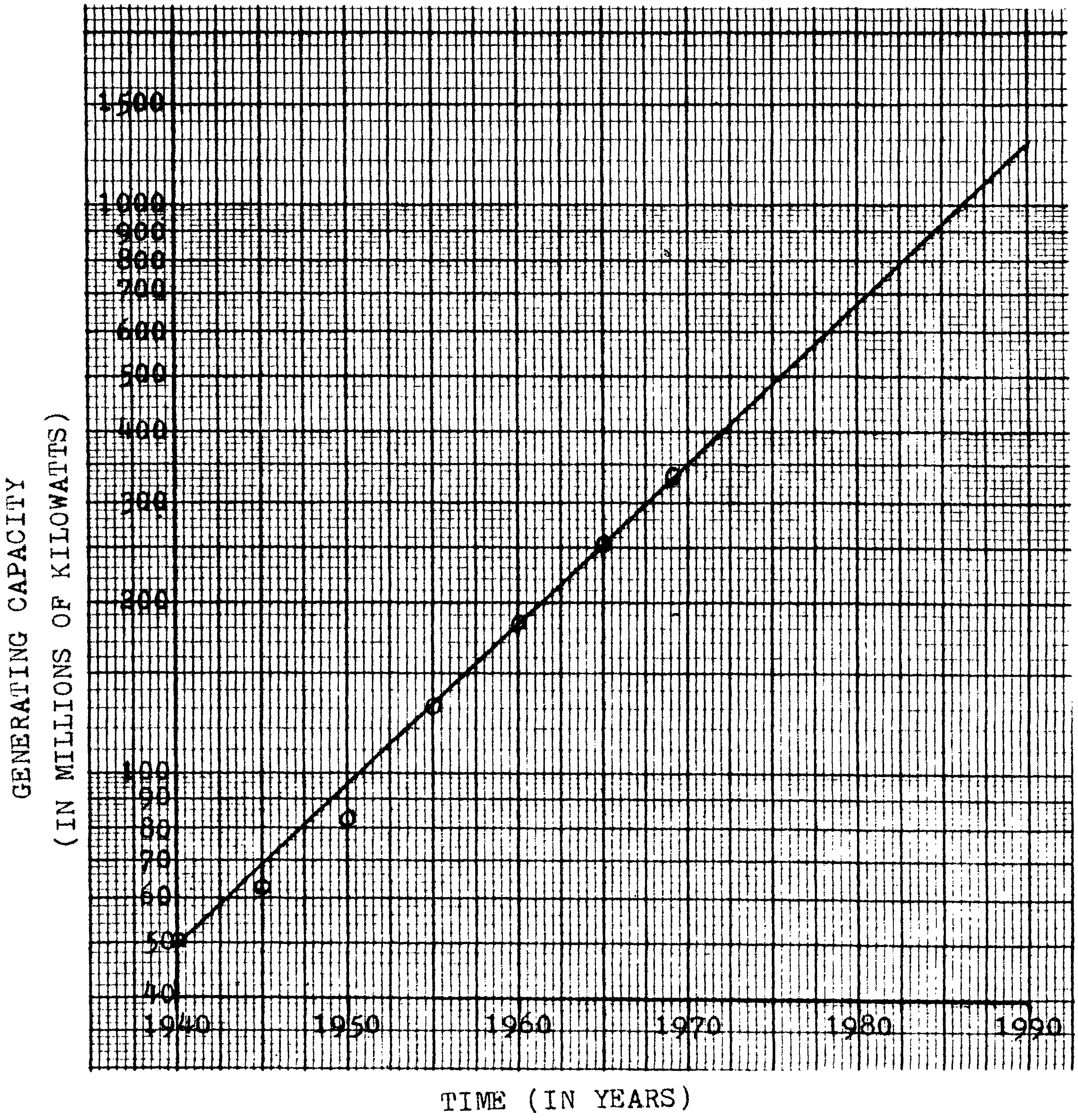

Fig. 2.--Free hand graph showing electrical generating capacity versus time projected to 1990.

KWH per year in 1970 (Figure 3).[3] The explanations for growing per capita power consumption are that electric power has always been available, reliable, and inexpensive.

The spectre of a national power crisis occurs when utilities cannot market power either because of prices which the consumer will not accept, or because of equipment limitations.

Power Production and Ecology

As the nations second largest industry, the electric power industry by 1980 will be consuming 500 million tons of coal, four trillion cubic feet of natural gas, 100 million barrels of residual oil and 20,000 to 30,000 tons of uranium to meet expected demands.[4] To protect our environment, pollutants from consuming these fuels must be minimized.

While electric power generation presently accounts for only 13 percent of the total pollutant tonnage, it is responsible for over 50 percent of the sulfur dioxide, 27 percent of the nitrogen oxides and 30 percent of particulate pollution. Electric utilities are now responsible for contaminating the atmosphere with 25 million tons of pollutants a year.[5] With demand for power increasing twofold every

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[3] Table 15 in Appendix I shows how per capita consumption has increased from 1940 through 1970.

[4] Lee Metcalf and Vic Reinemer, Overcharge, p. 3.

[5] Tom Alexander, "Some Burning Questions about Combustion," Fortune Magazine, February, 1970, p. 168.

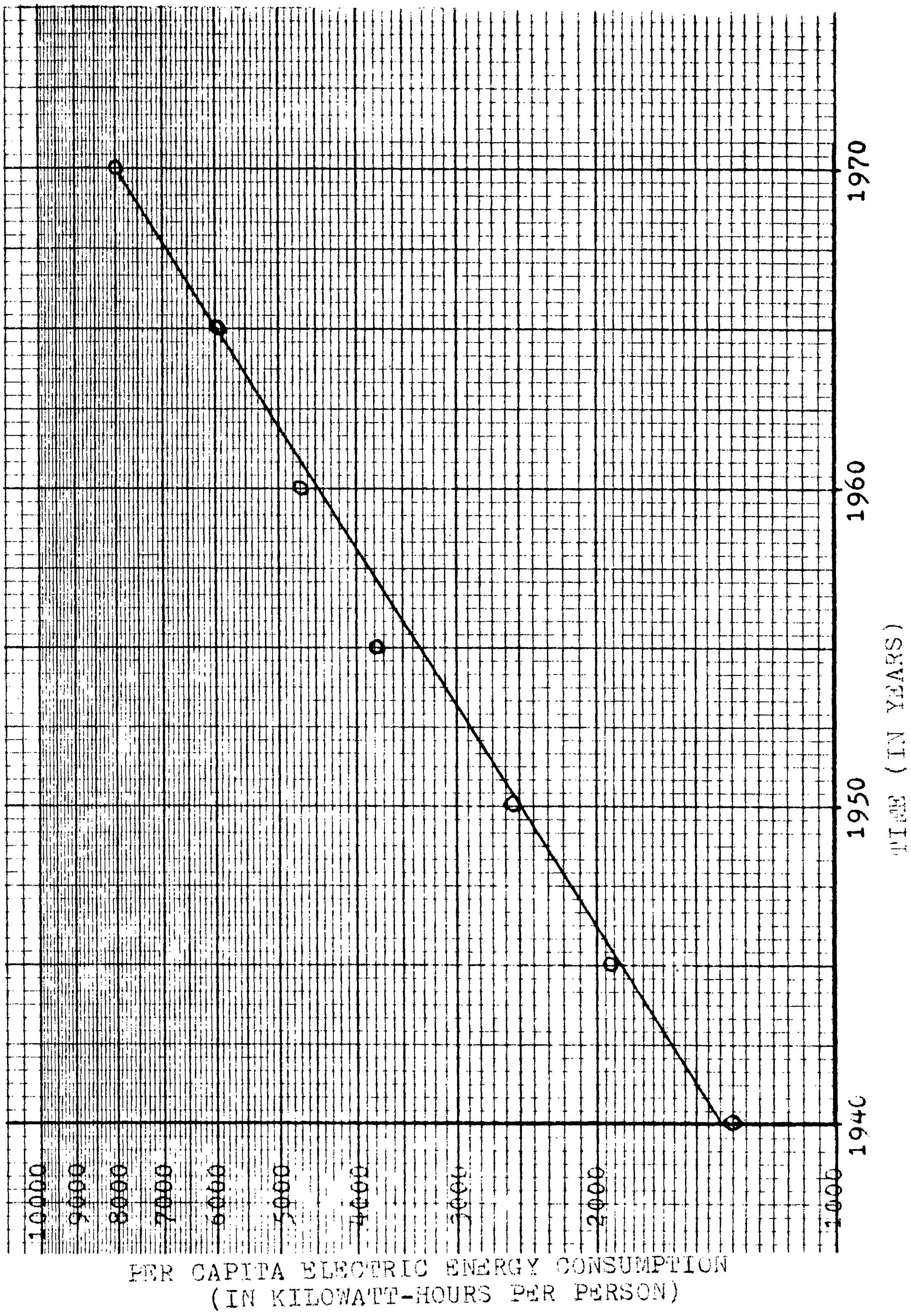

Fig. 3.--Free hand graph showing rise in per capita electric energy consumption 1940 - 1970.

decade the basis for environmental constraints on power production facilities is easily understood.

Nuclear plants have their own brands of pollution. Radioactive waste is the most dangerous pollutant and its handling is a costly problem now facing the Atomic Energy Commission. Thermal pollution from nuclear power plants is always more serious than from conventional plants because nuclear plants convert less heat into electric power. The excess heat not converted into power, must enter the environment. Citizen awareness of the deleterious environmental effects from nuclear plants has already resulted in legal actions which has prevented one plant from operating.[6]

Hydroelectric plants do not pollute like fuel-consuming power plants but they do effect fish and animal ecology. Many people feel they introduce scenic pollution or unsightliness into areas famous for scenic value. Construction of the High Mountain Sheep Dam on the Snake River in Idaho has been held up for over fifteen years because of the effect it may have on fish ecology, construction of a hydroelectric peak load plant on the Hudson River in New York has been blocked because it will detract from the natural beauty of the area.[7]

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[6] "Power Shortage gets Emergency Treatment," Business Week, May 16, 1970, p. 32; Consolidated Edison Company of New York was ordered by the court to cease opperation of its Indian Head Nuclear Plant after a Hudson River Valley citizens group declared the utility was damaging the environment.

[7] "The Environment Dilemma," Nations Business, Nov. 1970, pp. 50-57.

Nuclear Power Expectations Fall Short

Nuclear power plants were expected to account for 50 percent of the nation's electric generation capacity by the year 2000. However, labor problems, environmental problems, technical problems, and grossly underestimated costs, find nuclear power plants in 1971 contributing only two percent of the total electric power.[8]

Coal mine owners expecting nuclear plants to diminish domestic coal markets, contracted to sell vast quantities of coal abroad and also shut down some mines. Since nuclear plants did not develop as anticipated, additional fossil fuel power plants must be constructed to meet power demands. The fuel needed for conventional generating plants, however, is temporarily in short supply. As a result, in 1970 the power industry burned 7.8 million more tons of coal than was excavated that year. Stockpiles made up the difference. Demand for natural gas may exceed supply by ten percent in 1974.[9]

With nuclear plants making a slow entrance into the power generation industry it is apparent that fossil fuel generating plants will be in great demand for some years to come. The polluting effects from conventional plants will

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[8] A. Moore, "The Crisis in Power," Life Magazine, December 11, 1970, pp. 26F-31.

[9] "Face-to-face with the power crisis," Business Week, July 11, 1970, p. 52.

therefore be greater than anticipated because conventional plants must carry a greater share of the load than anticipated.

The spectre of a Power Crisis emerges as a double edged sword. One edge is honed by an expotentially increasing demand for power with limited fuel production while the other edge is honed by public demand for a better environment. The seriousness of the impending situation was indicated when President Nixon directed the Office of Emergency Preparedness to coordinate federal efforts toward averting a power shortage in the summer of 1970. The O.E.P. is the President's command center for dealing with civilian aspects of national emergencies.[10]

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[10] "Power Shortage Gets Emergency Treatment," Business Week, May 16, 1970, p. 32.

CHAPTER III

MHD A NEW CONCEPT FOR GENERATING POWER

A Technical Description

Magnetrohydrodynamics (MHD) is the electrical phenomenon which occurs when conducting fluids pass through a strong magnetic field. In conventional generating plants an armature is forced through a magnetic field inducing an electrical current in the armature. Similarly, if a conducting plasma (ionized gas) is forced through a strong magnetic field, currents are induced in the plasma.[1]

Plasma for a coal-fired MHD plant is a high temperature high pressure ionized gas formed by burning coal in air and adding seed materials which increase the plasma's electrical conductivity.[2] The plasma is forced through a channel surrounded by powerful electromagnets. Current induced in the plasma is drawn off the electrodes strategically located along the channel wall. MHD produces a direct

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[1] Winston H. Bostic, "Magnetohydrodynamics," Colliers Encyclopedia, 1966 ed., XV, 208-209.

[2] The MHD technique is not limited to ionized gases produced by fossil fuels. Any fluid, gaseous or liquid which exhibits the above mentioned electrical properties is eligible. However, this study will focus on MHD electrical power generation derived from high temperature ionized gases from the combustion of coal or char only.

current as opposed to the alternating current produced in most modern generating plants.

Typical MHD Power Plant

An MHD Power Plant must perform four basic functions:

(a) Produce a magnetic field.

(b) Produce a continuous high temperature plasma stream.

(c) Collect and distribute the developed electrical energy.

(d) Handle the by-products of these processes in a manner commensurate with economic and environmental standards.

A typical MHD generating plant will contain equipment for the following: fuel supply, combustion, seeding and seed recovery, power generation, air preparation, effluent cleaning, and chemical recovery.[3] A scematic drawing of an MHD power plant together with an artist's conception of one are presented in Figures 4 and 5.

A History of MHD Development

Major technological advances for fossil fuel MHD power generation were made at the AVCO Everett Research Laboratory, Everett Massachusetts. They were by-products

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[3] A detailed discussion of plant equipment is presented in Appendix II.

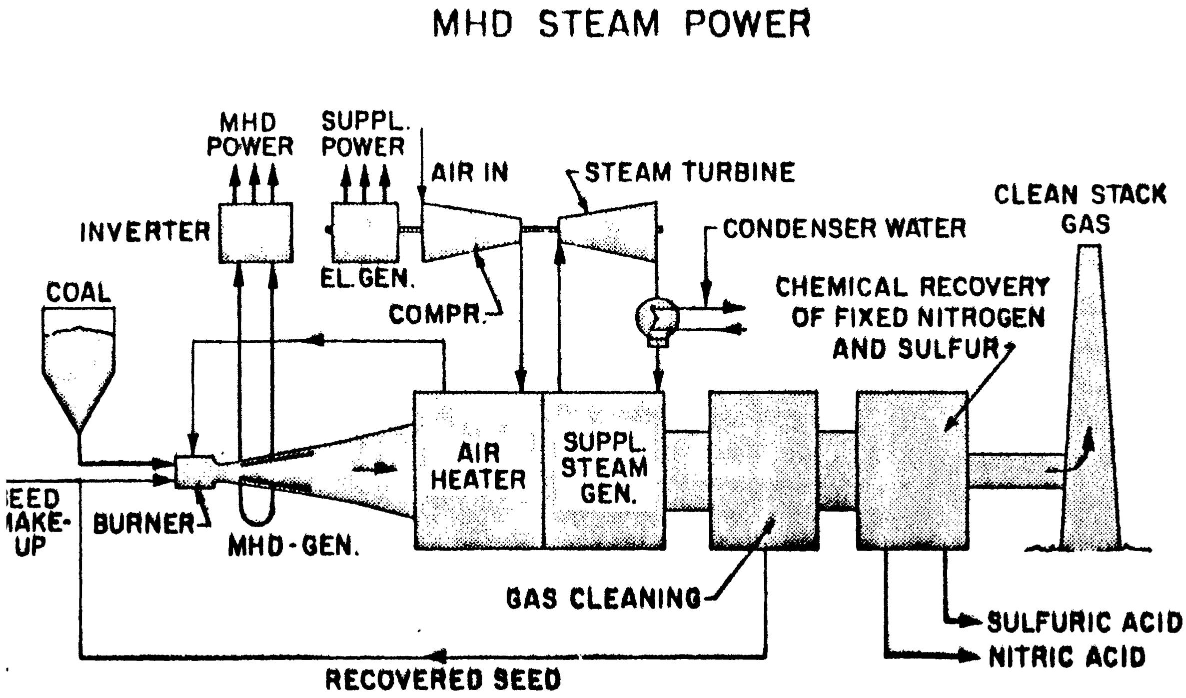

Fig. 4.--Schematic drawing of an MHD Power Plant.

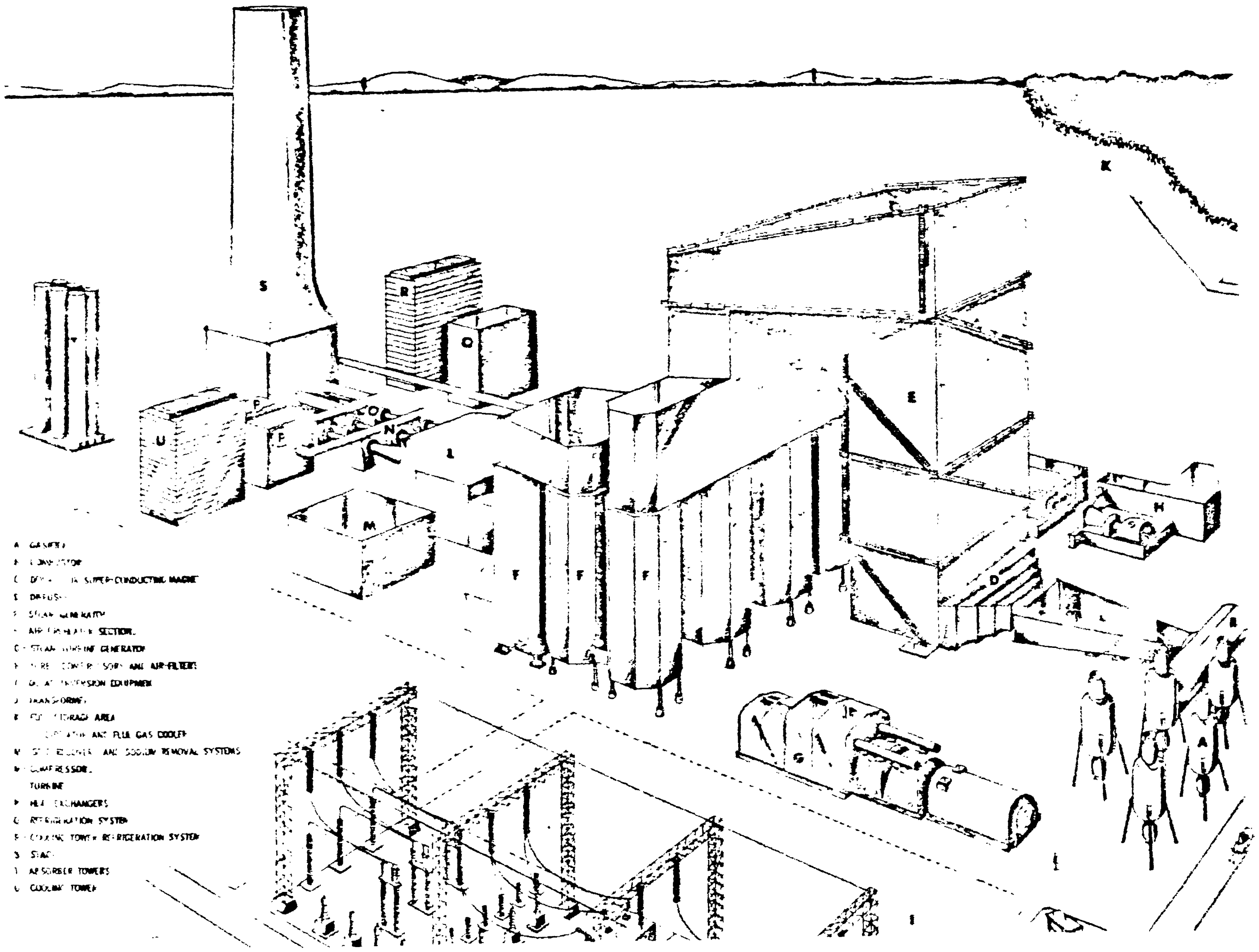

Fig. 5.--Artist's conception of an MHD Power Plant.

from research on ballistic missile reentry, lasers, and high temperature gas dynamics. AVCO constructed a prototype MHD generator in 1958 and in 1959 with the American Electric Power Service Corporation jointly examined MHD for base load power generation. Federal support began in 1962 with funding for a 20,000 kilowatt prototype at the USAF Arnold Engineering Development Center. This unit for the USAF LORHO project was completed in 1967. Another generator, the Mark V, in the 32 MW range was built by AVCO in 1965 under contract from the Advance Research Projects Agency of the Department of Defense. The LORHO generator was designed to operate for three minutes and the Mark V for one minute.[4] These units demonstrated the MHD concept to be sound. The AVCO Long Duration Test Facility has since proven continuous MHD operation possible.[5]

The next logical step in MHD development was construction of a small MHD power plant to test a continuously operating MHD generator using coal. Costs estimated at sixty-four million dollars, considered prohibitive at this time, will be required for such a research effort.

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[4] Ibid., pp. 12-31, passim.

[5] F. A. Hals, W. D. Jackson, S. W. Petty, R. J. Rosa, and J. Teno, MHD Power Generation Status and Prospects For Open-Cycle Systems, AVCO Everett Research Laboratory, November 1969, p. 3; AVCO has run MHD generators for 200 continuous hours and the Japanese have run MHD generators for 100 continuous hours.

The Soviet Union has recently taken the lead in MHD development using technology originally developed in the United States. The Soviet Union constructed the U-02 MHD Experimental Station in 1965. The U-02 test facility answered many technical questions for the Soviets and enough information was gathered to permit construction of the Soviet U-25 25 MW MHD pilot plant. The U-25 completed in 1970, is the world's first operational MHD power plant. The U-25 was designed to permit extensive testing and is expected to lead to design of large scale MHD central power stations by the end of 1973. Operation of the first Soviet MHD central station is estimated for the early 1980's. [6] The Soviet Union has an advantage over the United States in that they have available, abundant natural gas reserves and MHD using this cleaner fuel reduces equipment costs and technical problems.

Japan, Poland and West Germany are also researching MHD, but the Soviet Union has made the most progress toward a central station MHD power plant. Unless the United States accelerates MHD development efforts in the near future, the Soviet Union will most probably retain world leadership in MHD power plant development.

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[6] Report on Visit to Institute For High Temperatures, Moscow--to the Office of Coal Research, L. L. Newman, U. S. representative, August 31, 1970.

Current State of the Art and Unsolved Problems

MHD generators using gaseous fuel have been successfully developed and tested in both the United States and the Soviet Union. Complete development of a coal-fired MHD plant will require additional research and testing before becoming a reality.[7] The current state of development and existing problem areas vary for different stages of the MHD power production process. Following is a qualitative analysis of major MHD components.

Fuel and Seed--There are ample coal reserves to support an MHD power production process and no significant problems associated with feeding coal into the MHD combustion chamber. Creating the desired ionization characteristics for MHD generation has been the subject of considerable research and selecting a combination of fuel and seed is a more economic than technical problem. Seed costs must be weighed against seed recovery costs and many mixtures of fuel and seed must be analyzed before an optimal mixture is obtained. Economic and technical problems should be solvable in a pilot plant. Potassium and cesium are proven acceptable seeds.

MHD Channel Construction--There are three accepted MHD channel configurations, all of which are technically sound. Again a

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[7] Office of Science and Technology, Panel on Magnetohydrodynamics (MHD), MHD For Central Station Power Generation: A Plan For Action, June, 1969, pp. 16-23, passim.

pilot plant testing the different constructions is probably the best method for selecting the most efficient design. Sufficient research has been conducted to provide confidence in MHD channel construction. Some electrode and insulator materials for the MHD generator have been tested successfully at AVCO's Long Duration Test Facility. Materials inside the generator must possess desired conductive and electrical properties at extreme temperatures. The ablative effect of plasma and ash complicate material selection. Choosing MHD channel electrodes and insulators which can perform their function at elevated temperatures in the presence of ablative fluids requires additional research and development.[8] Continuous MHD operation cannot be accomplished until this problem is resolved. Materials such as zirconia, zirconium diboride and lanthanum compounds have been suggested for further research. Electrodes made of water cooled metal-mesh have also been suggested.[9] It is possible that inexpensive expendable channel liners can be developed, if so abrasion would no longer present a problem. Treating the plasma to reduce ablative effects is another possibility. Although material selection is a problem, there

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[8] U. S., Department of the Interior, Office of Coal Research, Feasibility Study of Coal Burning MHD Generation, February 1966, Vol. III, p. 9-2.

[9] Ibid., Vol. II, p. 164-167. passim.

are many possible solutions. Two thousand hours continuous channel operation has been attained using liquid fuels and 200 hours continuous channel operation has been attained with coal. Future research will be directed toward extending these times.

Combustion Chamber--Two suggested coal combustion methods involve (1) injecting pluverized coal with air into a flame holder chamber, (2) feeding char and air into a two-stage cyclone furnace. The cyclone furnace appears the most logical choice because it removes more ash from the system. To be successful, however, the cyclone furnace requires preheated air at high temperatures. Cyclone furnace technology is used in the steel industry and does not present any major problem in MHD development.[10]

Air Preheating--The channel exhaust gases provide sufficient heat for air preheating. The higher air can be preheated before entering the combustion process, the greater will be cycle efficiency. There appear to be no major problems designing air preheaters. Abrasion and particulate accumulation on heat exchange surfaces will be the most formidable technical problems with air preheater design.

Seed Recovery--The use of electrostatic and scrubbing operations should permit desired seed recovery. The degree of seed recovery depends upon which seed is used and its cost.

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[10] Ibid., Vol. II, p. 129-133.

Naturally, the more expensive the seed the more desirable recovery becomes. There are no technical problems associated with seed recovery. Recovery costs are an important consideration especially when recovery in the order of 99.5 percent is considered. Selecting the most economical seed recovery process will involve a careful cost analysis.

Air Pollution Control--Removing sulfur and nitrogen oxides from exhaust gases poses no problems. They can easily be combined with water to form acid. A problem will develop if no market exists for this acid waste. Hopefully there exists a product market for recovered air pollutants, if not, disposal will impose an additional cost.

Electrical Equipment--Recent developments with superconducting magnets and DC to AC inversion equipment have substantially reduced equipment problems. There presently exists all the necessary electrical hardware to produce and transmit MHD power.[11] Solid state inverters are now cost competitive with conventional ignitrons and both the United States and Japan have developed usable superconducting magnets.

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[11] Ibid., Vol. II, p. 249; The output of a proposed 400 megawatt MHD generator would be 10,000 amperes DC at 40,000 volts. There are no technical barriers associated with handling DC power of this magnitude.

CHAPTER IV

MHD-ECONOMIC CONSIDERATIONS

The Cost of MHD

There are no large operational MHD plants in the United States so plant and operating costs must be estimated. There are, however, acceptable data for making tentative cost estimates. First, many MHD plant components are common items in other generation systems. Secondly, extensive MHD research has been accomplished including plant costing. There are three cost categories analyzed in this paper: (1) development costs, (2) capital costs, and (3) annual production costs.

Private organizations have already spent over $17 million developing MHD,[1] but an additional $50 million to $100 million is required for further development before the first MHD central power station can be built. To bring United States MHD development up to the Soviet Union's level, will cost approximately $100 million.[2] Development

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[1] U. S. Congress, Senate, Committee on Interior and Insular Affairs, Magnetohydrodynamics (MHD), Hearings, before the subcommittee on Minerals, Materials, and Fuels, Senate, 91st Cong., 1st sess., December 18, 1969, p. 36-37.

[2] Ibid.

costs include an expensive MHD pilot plant. The $100 million estimate includes initial development costs of $2 million to $3 million a year increasing gradually over a six year period until a $64 million pilot plant is constructed.[3]

Low capital costs depend on obtaining maximum efficiency from an MHD generating plant. To achieve this, hot exhaust gases from the MHD process should be used as the heat source for a conventional steam-generating unit. Thus, MHD plants will ideally be the topping plant in an MHD-steam combination generating plant.[4]

Capital costs (Table 1) for an MHD-steam combination plant would be approximately $104 per kilowatt for coal-fired plants and $95 per kilowatt for char-fired plants. These cost estimates are based on the purchase of several 800 MW units.[5] MHD scientists state that MHD plant costs will initially be very close to steam generation plant costs of identical size and less than nuclear plant costs. As MHD

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[3] Ibid.; Review of the 50 Megawatt Experimental Pilot Plant Program at AERL, AVCO Everett Research Laboratory, Everett, Massachusetts, p. 9; An MHD plant 1/10 the size of a typical operational central power station is suggested for a pilot plant.

[4] Office of Science and Technology, Panel on Magnetohydrodynamics (MHD), MHD For Central Station Power Generation: A Plan For Action, June 1969, p. 1.

[5] U. S. Department of the Interior, Office of Coal Research, Feasibility Study of Coal Burning MHD Generation, February 1966, II, 42.

Table 1

Capital Cost Comparisons for 800 Mw Conventional And MHD-Steam Combined Plants (Millions of Dollars)

Account*	Conventional
311	6.337
312	40.104
314	18.241
315	3.281
316	0.813
353	3.700
Sub-total	72.476
Construction overhead	6.523
Grand Total	78.999
Dollars/kw	98.75
Dollars/kw G.T.bottom	

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*FPC accounts are 311, Structures and Improvements; 312, Boiler Plant Equipment; 314, Turbine Generator Units; 315, Accessory Electrical Equipment; 316, Miscellaneous Electrical Equipment; and 353, Switchyard.

+Char handling.

Note: Dual figures for MHD plants represent high and low cost estimates.

Table 1--Continued

	Combined-coal		Combined-char	
	5.142		5.142	
	17.993		17.993	
	9.699		9.699	
	2.472		2.472	
	0.813		0.813	
	1.850		1.850	
Duct	1.000	0.858	0.745	0.640
Diffuser	0.683	0.480	0.683	0.480
Combustor	1.500	0.702	2.700	1.902
Compressor	3.770	3.770	3.770	3.770
Foundation	0.300	0.200	0.300	0.200
Piping	0.200	0.100	0.200	0.100
Magnet	7.940	7.100	6.620	5.920
Preheater	6.500	3.000	3.617	2.400
Inverter	5.600	4.800	5.600	4.800
Switchyard	1.850	1.200	1.850	1.200
Seed collection	10.000	5.000	10.000	5.000
Carbonizer	5.000	4.500	1.000$^+$	0.500$^+$
	82.312	69.679	75.054	64.881
	7.408	6.270	6.755	5.840
	89.720	75.949	81.809	70.721
	112.15	94.94	102.26	88.40
	112.64	94.89	102.45	88.15

technology improves, capital costs for MHD will drop significantly below capital costs for conventional steam and nuclear plants (Figure 6).

Production costs are dependent upon technological progress in the development phase. If MHD duct lining must be replaced frequently, maintenance costs could be very high. It is expected that duct lining life will exceed one year for an 800 Mw plant with resulting operation and maintenance costs between 0.35 and 0.45 mills per kilowatt-hour. Total production costs which include operation costs, maintenance costs, seed costs and fuel costs are expected to be between 1.74 and 1.82 mills per KWH.[6] Total costs for owning and operating several 800 Mw MHD hybrid plants are shown in Table 2. Expected costs for a 1,000 Mw MHD plant in comparison with other generating methods and at two stages of MHD development are shown in Table 3.

In summary, the costs of developing and operating 800 Mw MHD generating facilities are estimated to be:

(1) Development costs $100 million.

(2) Capital costs $95 - $112 per KW capacity.

(3) Production costs 1.74 - 1.82 mills per KWH.

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[6] Ibid., Vol. I, p. 45.

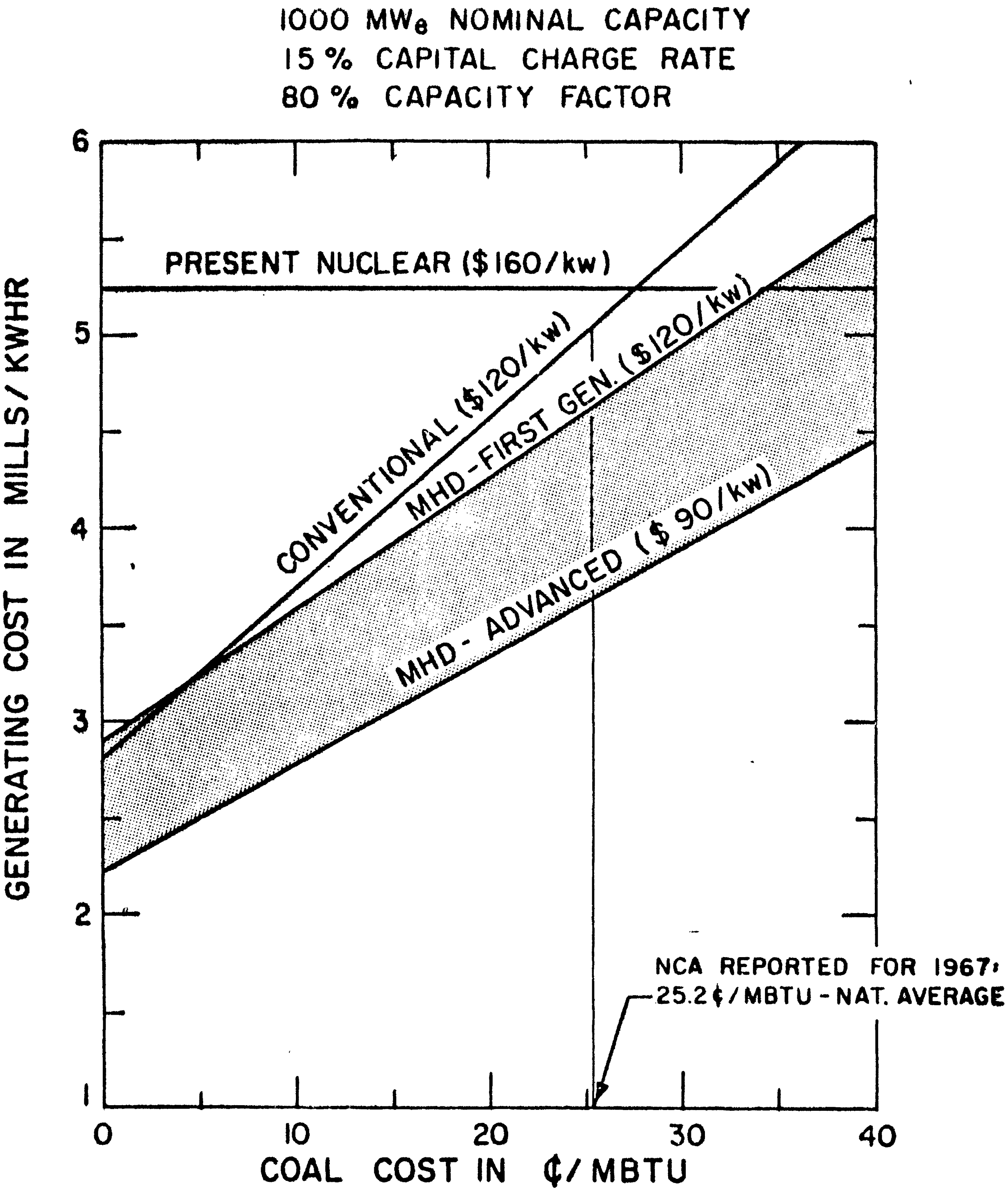

Fig. 6.--A comparison of MHD generating costs with conventional steam and nuclear generating costs.

Table 2

Cost of Owning and Operating Several 800 Mw Plants
(Mills per Kilowatt-Hour)

	Conventional		Combined (range of costs given)			
	Steam	Nuclear	Coal (steam)	Char (steam)	Coal (G.T.)	Char (G.T.)
Capital[a]	1.76	2.01	2.00 - 1.69	1.83 - 1.58	2.01 - 1.69	1.83 - 1.57
O & M[b]	0.35	0.35	0.45 - 0.35	0.45 - 0.35	0.45 - 0.35	0.45 - 0.35
Seed			0.01 - 0.06	0.02 - 0.08	0.01 - 0.06	0.02 - 0.08
Total less fuel	2.11	2.36	2.46 - 2.10	2.30 - 2.01	2.47 - 2.10	2.30 - 2.00
20 cent fuel[c]	1.70	1.65	1.36 - 1.36	1.31 - 1.31	1.39 - 1.39	1.33 - 1.33
Total	3.81	4.01	3.82 - 3.46	3.61 - 3.32	3.86 - 3.49	3.63 - 3.33

Source: Feasibility Study of Coal Burning MHD Generators, Department of the Interior Contract No. 14-01-0001-476.

[a] Fixed charges of 12½ percent on capital investment are assumed.

[b] Plant operating at 80 percent load factor.

[c] Fuel costs can be lowered up to 40 percent if plants are located at mine-mouth.

NOTE: The two columns listed under each fuel represent high and low estimates.

Table 3

Comparative Generating Costs of 1000 MW_e (Nominal) Power Plants

	Coal-Fired			Nuclear
	MHD		Conventional	Present
	First Gen.	Advanced		
Efficiency %	50	60	40	32
Capital Cost $/kW	120	90	120	160
Energy Cost - Mills/kWhr				
Capital Charges*	2.57	1.93	2.57	3.43
Fuel ($0.20/M Btu)	1.36	1.14	1.70	1.50
Operation and Maintenance	0.25	0.25	0.25	0.30 (inc. ins.)
Seed	0.08	0.02	—	—
	4.26	3.34	4.52	5.23

*Capitalized at 15% and 80% plant capacity factor.

Environmental Aspects

Reduced atmospheric contamination is one of the most significant arguments in favor of MHD. Existing power production facilities account for 13 percent of all air pollution. Air pollution was a price paid for power but power demands are increasing while tolerance for pollution is decreasing. The solution to this problem is either lower production or cleaner production.

Burning the same grade coal as conventional steam power plants, MHD plants reduce particulate pollutants by 91 percent, sulfur oxide pollutants by 99.3 percent and nitrogen oxide pollutants by 92 percent (Table 4). The MHD process requires all exhaust gases to be treated before going up the stack. Thermodynamically, MHD operates more efficiently than present power plants. An MHD plant can produce the same amount of power as a conventional steam-generating plant with 30 percent less fuel.[7] If MHD replaces conventional coal-fired generating plants as the primary power production method, power demands could be met and the degree of air pollution would actually decline.

MHD not only reduces air pollution but reduces thermal pollution as well. The process develops more power per pound of coal burned, therefore less energy is lost as

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[7] Appendix III proves how MHD operating at maximum efficiency uses 30 percent less fuel than conventional steam plants operating at maximum efficiency.

Table 4

Comparison of Stack Emission From Conventional Steam Power Plants and MHD Power Plants

Basis for Comparison:

Power Plant Capacity 1000 MW

Coal containing 3% sulfur burned with air*

Pollutants Emission in Tons Per Day

	Conventional Steam	MHD	Decrease
Particulate Matter	33[a]	3[b]	91.0%
Sulfur Oxides (SO_2)	450[c]	3[d]	99.3%
Nitrogen Oxides (NO_x)	80[c]	4[e]	92.0%

Source: Hearing before the subcommittee on minerals, materials, and fuels, of the Committee on Interior and Insular Affairs, United States Senate, 91st Congress, 1st session, p. 15.

*Montana coals contain less than one percent sulfur resulting in even less pollution.

[a] Recommended dust emission control in accordance with ASME standard No. APS-1, November 1968.

[b] 99.9% efficient seed recovery and gas cleaning system.

[c] Emission factors from Public Health Service Publication No. 999-AP-42.

[d] 25 ppm SO_2 in effluent gas from chemical recovery system.

[e] 50 ppm NO_x in effluent gas from chemical recovery system.

heat carried away by a cooling system. Although MHD does have definite environmental advantages over conventional power production methods the system contains potential dangers to our environment which must be acted upon and eliminated.

Large scale MHD power production will necessitate accelerated coal mining operations. Adequate safeguards must be instituted to insure that coal mining operations do not damage the environment in the future as they have in the past.

A Comparison of MHD With Other Power Generating Methods

There are many methods for producing electricity. Steam, hydroelectric and nuclear power generating plants are the most common. In each method energy is converted from one form into another. Steam generating plants for example, convert the chemical energy in coal into thermal energy (heat), the thermal energy is transformed into kenetic energy (the energy of motion) by heating water to steam which is used to set a turbine in motion. The turbine is connected to an armature. When the armature is forced through a magnetic field, by the rotating turbine, electrical energy is produced in the armature. What began as chemical energy, ended as electrical energy. Hydroelectric power generation is very similar in that the kenetic energy of a turbine is used to drive an armature through a magnetic field to produce electrical energy. It differs only in the fact that the kenetic energy of the turbine is derived from the potential energy stored in a huge column of water backed up behind a dam. Nuclear power plants make use of nuclear energy released during the breakdown of unstable atoms, to heat water to steam which drives the turbines that produce electrical energy. The difference between nuclear plants and conventional steam plants is only in the method used to heat the water. MHD uses thermal energy to create an ionized plasma. Currents are induced in the plasma when the plasma is passed through a magnetic field. The plasma in MHD performs the function of the armature in conventional power plants.

An analysis of the most common power production methods as to relative cost, efficiency, and environmental effects is provided to evaluate each.

Hydroelectric Plants

There are approximately 1200 hydroelectric generating plants in the contiguous United States but 388 of them produce 96 percent of the net generation. These plants possess 18 percent of the nation's electric utility generating capacity.[8]

Investment costs per kilowatt capacity are normally higher for hydroelectric plants for several reasons. Often

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[8] Federal Power Commission, Hydroelectric Plant Construction Cost and Annual Production Expenses, Twelfth Annual Report 1968, 1970, p. vii.

the plants are multi-purpose and include investment not attributable to power generation such as flood control, recreation facilities, relocation of highways, new roads, and back water purchases. Investment costs for hydroelectric projects vary from $90 per KW capacity to over $600 per KW depending upon their location and objective.

Hydroelectric production expenses are divided into operational and maintenance expenses and range from 0.13 mills/KWH to 1.63 mills/KWH.

Tabulated cost data for over twenty hydroelectric power systems which include 428 separate facilities are shown in Table 5. These cost data represent a mix of single-purpose, multi-purpose and peak-load hydroelectric facilities. Plant costs average $243 per KW installed capacity and operating expenses 0.53 mills per KWH net power production.[9]

It is difficult to compare a hydroelectric power plant efficiency with a thermal-electric generating plant since the energy conversion process in hydroelectric does not involve heat, but the conversion of potential energy in the water to electrical energy in the turbine is over 90 percent. It must be realized that hydroelectric plants have extremely limited application. Plant location is a severe constraint while plant location is not as constraining for other power production methods. Hydroelectric peak-load

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[9] Ibid., p. xi, v.

Table 5

Hydroelectric Plant Costs and Expenses For 21 Selected Systems

System	Investment Costs: Installed Capacity (MW)	Investment Costs: Cost Dollars /KW
Alabama Power Company	1,302.2	222
City of Los Angeles Dept. of Water and Power	234.3	295
Pacific Gas and Electric Co.	2,274.6	277
Southern Calif. Edison Co.	720.4	295
Georgia Power Company	433.2	180
Idaho Power Company	1,289.3	196
The Washington Water Power Company	636.5	231
Central Maine Power Co.	264.6	256
New England Power Co.	463.2	199
Minnesota Power and Light Company	106.2	205
The Montana Power Co.	469.9	131
Niagara Mohawk Power Corp.	652.4	207
Power Auth. of the State of New York	3,106.0	344
Duke Power Company	868.7	120
Pacific Power & Light Co.	867.8	248
Portland General Elec. Co.	534.4	247
T.V.A.	3,102.2	172
P.U.D. No. 1 of Chelan County	975.3	286
P.U.D. No. 2 of Grant County	1,619.8	270 (est)
Puget Sound Power & Light Co.	297.1	255
City of Seattle, Dept. of Lighting	1,070.3	228
Total (21 systems)	21,288.0	243

Source: Hydroelectric Plant Construction Cost and Annual Production Expenses, 12th Annual Supplement 1968, Federal Power Commission.

Table 5--Continued

	Production Costs	
Operation Costs Mills/net KWH	Maintenance Costs Mills/net KWH	Total Prod. Costs Mills/KWH
0.40	0.25	0.65
0.64	0.50	1.14
0.53	0.30	0.83
0.65	0.73	1.38
0.51	0.60	1.11
0.18	0.07	0.25
0.39	0.10	0.49
0.93	0.49	1.42
1.02	0.63	1.64
0.75	0.18	0.93
0.39	0.10	0.49
0.65	0.43	1.08
0.06	0.07	0.13
1.02	0.48	1.50
0.33	0.19	0.52
0.59	0.18	0.77
0.37	0.20	0.57
0.24	0.09	0.33
0.16	0.06	0.22
0.49	0.47	0.96
0.29	0.15	0.44
0.33	0.20	0.53

pumping plants are the most inefficient power production plants of all. It takes more power to pump water into the reservoir than is generated by the turbines. The advantage to this system is that low cost power available during slack hours can be used to pump water into a reservoir which in turn is used to generate electricity during peak-load hours.

There are many environmental effects which must be carefully considered before constructing hydroelectric plants. Because hydroelectric plants differ so much in construction and purpose they must be analyzed individually with reference to environmental impact. Large hydroelectric facilities often create beautiful recreation areas and establish excellent flood control programs, but construction of large dams of the Hoover, Hungry Horse and Grand Coulee type are the exception rather than the rule.

Of all power production methods hydroelectric is the least expensive and has the least deliterious effect on environment. Hydroelectric power, however, has the most severe restrictions regarding plant location, and the number of hydroelectric dams possible is limited by topography.

Conventional Fossil-Fueled Steam-Electric Generating Plants

Conventional steam generating plants account for over 80 percent of total power generating capacity and over 82 percent of total power production. In 1969, conventional steam generating plants produced approximately 1,183 billion kilowatt-hours of electricity as compared with 250 billion KWH for hydroelectric plants and eight billion KWH for nuclear plants. Recent developments indicate that conventional steam generating plants will continue to be favored by electric utilities. During 1968 new orders for plants with capacities over 500 MW were placed for seventeen nuclear-fueled generating plants but in August 1969 orders for nuclear-fueled generating plants stood at only three for the year as nuclear plant construction costs greatly exceeded original estimates.[10] The average size of conventional steam generating plants also continues to grow. In 1957 the average unit was 96 MW but by 1968 the average unit was rated at 231 MW. The total number of plants has actually been decreasing since 1938 as capacity increased (Table 6).

Costs of steam generating plants are divided into two categories: (1) plant costs and (2) production costs. Plant costs represent invested plant capital as a function of generating capacity. Production costs include operating costs, maintenance costs, and fuel costs and are expressed in terms of mills per net kilowatt-hour output. Since there are many types of fuels and quality varies widely even among similar types, prices are normally expressed as a function of cost per unit heat produced (cents per million B.T.U.).

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[10] Federal Power Commission, Steam Electric Plant Construction Costs and Annual Production Expenses Twenty-First Annual Supplement 1968, 1969, p. vi.

Table 6

Conventional Fossil-Fueled Steam-Electric Generating Plants, Capacities, and Annual Kilowatt-Hour Production For the Total Power Industry

	1938	1947	1957	1967[a]	1968[b]
Number of plants	1,165	1,045	1,039	971	979
Installed capacity, megawatts	26,066	36,035	99,500	210,237	226,020
Average plant size, megawatts	22	35	96	217	231
Net generation, billion kilowatt-hours	68.4	174.5	497.2	974.1	1,072.9
Approximate average annual plant factor (percent)	35	55	57	53	54

Source: FPC Steam Electric Plant Construction Cost and Annual Production Expenses, Twenty-First Annual Supplement.

[a] Excludes 13 nuclear plants totaling 2,887 megawatts, generating 7.7 billion kwh; 1 small geothermal plant (55 megawatts) and 135 gas turbine generator installations or plants totaling 3,270 megawatts, generating 1.7 billion kwh. (The nuclear plant totals include the Connecticut Yankee and San Onofre plants shown on pages 151 and 154 of this report.)

[b] Excludes 12 nuclear plants totaling 2,817 megawatts, generating 12.3 billion kwh; 1 small geothermal plant (83 megawatts) and 191 gas turbine generator installations or plants totaling 6,053 megawatts, generating 3.9 billion kwh. (Preliminary totals).

Since MHD plant costs were estimated for large facilities, cost data for steam generation plants were based on an analysis of only the fifteen largest plants in the United States.

Plant costs for large steam plants average $112 per megawatt capacity (Table 7). Unlike costs in most other industries, plant costs in the power generation industry are not rising rapidly. Cost stability is attributable to the larger average size of new generating units, use of outdoor or semi-outdoor construction of generating equipment, wide spread adoption of unit-type construction, and central control room operation. Plant construction costs decreased each year from 1961 through 1965 but have increased slightly since 1966.[11]

Fuel costs account for almost seventy-eight percent of total electrical energy production expense. Labor costs are the next highest production expense followed by plant operating supplies, materials, office expenses, renewal parts and materials. Production expenses like plant costs have been very stable. Operation costs have decreased steadily since 1965 while maintenance costs have remained almost constant (Table 8). Fuel costs decreased steadily from 1956 through 1966 but have begun to rise in the past four years.[12] One factor contributing to this favorable cost

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[11] Ibid., p. vii.

[12] Ibid., p. xvi.

Table 7

Cost and Operating Expenses for the 15 Largest Fossil Fuel Fired Generating Plants In the United States

Plant Name - State	Maximum Capacity MW	Plant Cost Dollar/KW	Operating Expenses Mills/KWH
Moss Landing (Calif)	2175	94	.15
Alamitos (Calif)	1982	91	.13
Widows Creek (Ala)	1978	110	.25
Keystone (Pa)	1872	95	.18
Joliet (Ill)	1862	111	.24
Ravenswood (N.Y.)	1828	154	.24
Shawnee (Ky)	1725	120	.20
Kingston (Tenn)	1700	112	.28
Oak Creek (Wisc)	1670	121	.30
Haynes (Calif)	1606	106	.17
Redondo Beach (Calif)	1604	100	.25
Astoria (N.Y.)	1551	174	.59
P. H. Robinson (Tex)	1550	- -	.09
Johnsonville (Tenn)	1485	109	.30
Muskingun River (Ohio)	1467	119	.22
Average	----	114.5	.24

Source: Steam Electric Plant Construction Cost and Annual Production Expenses, Twenty-First Annual Supplement, FPC.

Table 7--Continued

Maintenance Expenses Mills/KWH	Production Expenses Less Fuel Mills/KWH	Fuel Costs M/KWH	Total Production Expense
.13	.28	3.00	3.28
.26	.39	2.87	3.26
.39	.64	2.00	2.64
.41	.59	1.82	2.41
.38	.62	2.29	2.91
.24	.48	3.74	4.22
.22	.42	1.74	2.16
.33	.61	2.09	2.70
.40	.70	2.85	3.55
.28	.45	2.82	3.27
.30	.55	2.95	3.50
.96	1.55	3.97	5.52
.09	.18	1.91	2.09
.34	.64	1.88	2.52
.62	.84	1.79	2.63
.35	.59	2.54	3.13

Table 8

Weighted Average Annual Production Expenses for Conventional Fossil-Fueled Steam-Electric Plants Reported in Steam Plant Cost Books--1956 to 1968, Inclusive

Year	Megawatts	Net Generation, Billion Kilowatt-Hours	Mills Per Kilowatt-Hour				
			Operation	Maintenance	Subtotal	Fuel	Total
1956	81,700	446.0	0.48	0.39	0.87	2.87	3.74
1957	88,700	470.6	0.49	0.39	0.88	3.02	3.90
1958	98,600	470.7	0.51	0.40	0.91	2.94	3.85
1959	109,500	532.2	0.47	0.38	0.85	2.82	3.67
1960	120,100	566.5	0.47	0.38	0.85	2.81	3.66
1961	131,600	599.5	0.44	0.37	0.81	2.78	3.59
1962	139,200	636.0	0.42	0.37	0.79	2.75	3.54
1963	147,000	695.5	0.40	0.35	0.75	2.66	3.41
1964	157,300	752.2	0.38	0.36	0.74	2.64	3.38
1965	165,600	796.9	0.38	0.37	0.75	2.60	3.35
1966	177,500	897.8	0.37	0.36	0.73	2.61	3.34
1967	192,372	930.4	0.38	0.39	0.77	2.65	3.42
1968	208,966	1,026.7	0.37	0.38	0.75	2.68	3.43

Source: Steam-Electric Plant Construction Cost and Annual Production Expenses, Twenty-First Annual Supplement, 1968, FPC.

situation was a sharp reduction in the number of employees per megawatt capacity. For example, in 1950 new plants required a one man to one megawatt ratio. By 1969 this ratio had dropped to 0.20 to 1.0. Higher temperatures and pressures now allow greater efficiency and economies of scale are attained through increased plant capacity. In 1969 there were 140 fossil fueled plants of 500 megawatts and larger but in 1948 there were only two. The large generating plants illustrated in Table 7 average production expenses of 0.59 mills per KWH and fuel costs of 2.51 mills per KWH, operating costs of 0.23 mills per KWH and maintenance costs of 0.36 mills per KWH. There is no basis to expect any sharp rise in production costs. Fuel costs may rise in the near future as demand for coal leads production, but this should only be a temporary problem since the nation has vast coal reserves. As of 1968, coal was used in 66 percent of fossil fueled steam electric power generation, natural gas for 26 percent, and residual oil for eight percent. The fuel costs from 1960 through 1968 (Table 8) were very stable.

The efficiency with which heat can be converted into electrical energy, is a function of the maximum temperature present in the conversion system. Steam has an upper temperature limit of 1050°F. The maximum efficiency attainable at this temperature is 42 percent. The higher temperature

MHD system is therefore capable of greater efficiencies, that is, less fuel is required to produce a given amount of electricity.

The polluting emissions from conventional steam plants are a matter of great concern. The growing demand for power necessitates greater environmental safeguards. A conventional steam plant emits eleven times the particulate matter, one hundred fifty times the sulfur oxides, and twenty times the nitrogen oxides of an equal size MHD plant. Cooling requirements for conventional steam plants are greater than for MHD because less heat is converted into electrical energy. Fuel treatment costs to reduce pollutants are quite high. Desulfurizing oil and coal increases the price ten percent and removing SO_2 from stack gas raises production costs ten percent to twenty percent.[13] It is the harmful effects which conventional steam generating plants have on our environment which necessitate finding alternative power producing methods. Pollution has always been a power generation by-product; there now exists the opportunity to eliminate this unfavorable consequence without increasing costs.

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[13] Tom Alexander, "Some Burning Problems About Pollution," Fortune Magazine, February 1970, p. 168.

Nuclear Powered Steam Generating Plants

Fuel costs for nuclear plants are expected to become so low that nuclear plants of the future may have a negligible fuel cost. First generation nuclear powered plants use uranium in the plants nuclear reactor. This fuel is expensive and in the past twenty years over one percent of the nation's reserves have been consumed.[14] However, research is progressing on a nuclear fast-breeder reactor which has the capability of producing its own supply of nuclear fuel. Nuclear fuel is produced by bombarding a non-radioactive element like thorium with the emissions from a radioactive element like plutonium. The thorium becomes radioactive as a result of this process and the quantity of nuclear fuel is increased. One pound may be increased to two in seven to ten years.[15] The minerals amenable to this fast-breeder reaction are abundant and relatively inexpensive.[16]

The Federal Government has realized the potential of nuclear steam power plants and has spent over $2 billion for research and development of this concept. It was hoped that by the year 2000 nuclear steam generating plants would

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[14] A. Moore, "The Crisis in Power," Life Magazine, December, 1970, pp. 25F.

[15] Glenn T. Seaborg and Justin L. Bloom, "Fast Breeder Reactors," Scientific America, November, 1970, p. 13.

[16] Montana is one of the states rich in thorium.

provide fifty percent of the nation's electric power.[17] It is unlikely that this goal will be realized. Public utilities are refusing to buy nuclear plants as costs have skyrocketed over original estimates. Huge federal subsidies and development grants are still required to make nuclear plants competitive. There were, however, fifty-eight nuclear power plants either in testing, under construction or on order in 1969, representing 66,000 MW or eighteen percent of present capacity.[18]

Plant costs and production costs were computed for eight operational nuclear power plants and cost data do not include federal subsidies for fuel and construction. Large plants yielded significantly lower capital costs. Plant costs ranged from $160 per KW installed capacity to $468 (Table 9). The weighted production expenses were 5.37 mills per net KWH with operating expenses of 0.88 mills per KWH, maintenance expenses 0.54 mills per KWH, and fuel costs of 2.53 mills per KWH. Fuel costs are understated since they do not include costs incurred by the Atomic Energy Commission (AEC). Although fuel costs presently range between 1.69 mills per KWH and 4.48 mills per KWH the coming-of-age

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[17] A. Moore, "The Crisis in Power," Life Magazine, December, 1970, pp. 26 F.

[18] Federal Power Commission, Steam-Electric Plant Construction Costs and Annual Production Expenses, Twenty-First Annual Supplement 1968, 1969, p. xiii.

Table 9

Costs and Operating Expenses for 8 Operational Nuclear-Steam Generating Plants

Plant Name	State	Maximum Capacity MW	Plant Cost Dollar/KW	Operating Expenses Mills/KWH
Rowe	Mass	185	214	.83
Connecticut Yankee	Conn	600	153	.43
Indian Point	N.Y.	275	468	1.09
Peach Bottom	Pa	46	231	8.63
Big Rock Point	Mich	75	185	1.31
Dresden	Ill	209	160	.93
San Onofre	Calif	450	180	.79
Humbolot Bay	Calif	60	377	.87
		1900	210	.88

Source: Steam Electric Plant Construction Cost and Annual Production Expenses, Twenty-first Annual Supplement, FPC.

Table 9--Continued

Maintenance Expenses Mills/KWH	Production Expenses Less Fuel Mills/KWH	Fuel Costs Mills/KWH	Production Expenses	Year
.40	1.23	2.52	3.75	1961
.25	.68	1.69	2.37	1968
.78	1.87	3.28	5.15	1962
4.76	13.39	3.06	16.45	1967
.72	2.03	3.11	5.14	1962
.90	1.83	3.10	4.93	1960
.39	1.18	2.31	3.49	1968
.42	1.29	4.48	5.77	1963
.54	1.42	2.53	5.37	

of nuclear fast breeder reactors is expected to lower fuel costs initially by approximately fifteen percent and later by approximately thirty percent.[19] Research and development expenses incurred by A.E.C. alone on fast-breeder reactors are expected to exceed $2 billion.[20]

The efficiency with which heat is converted into electricity is relatively low for nuclear fuel steam generating plants. Efficiencies in the order of thirty-three percent are considered good. This low efficiency means that larger cooling systems are required per KW capacity, than with more efficient generating plants.[21] The lower efficiency of nuclear units increases cooling system costs but it is hoped that reduction in fuel costs will offset this increased cost. Since nuclear fuel generating plants use steam as the working fluid, maximum efficiency is the same as for conventional steam plants, i.e., forty-two percent. It is possible for nuclear plants to approach this maximum efficiency just as modern conventional steam plants do now.

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[19] Glenn T. Seabourg and Justin L. Bloom, "Fast Breeder Reactors," Scientific America, November, 1970, p. 21; Seabourg and Bloom place present nuclear fuel costs at 5 mills to 10 mills per KWH. Percentage savings are based on these fuel cost figures.

[20] Ibid. Net savings from this multi-billion dollar development effort could exceed $200 billion by the year 2020 provided the fast breeder reactors are operational by 1984.

[21] John R. Clark, "Thermal Pollution and Aquatic Life," Scientific America, March, 1969, p. 19.

Nuclear steam generating plants create two environmental hazards, thermal pollution and radiation poisoning.

Thermal pollution is the heating effect which power plants have on waters used to cool them. Nuclear plants are not as thermally efficient as conventional power plants, as a result, they waste sixty percent more thermal energy than conventional steam plants.[22] The thermal energy in any power plant not converted to electric energy, is ejected as heat. If nuclear plants are to take over the burden of power production as presently planned, within thirty years the electric power industry will be producing approximately two million MW of electricity with (20 x 10^{15}) BTU's of waste heat per day. The cooling water necessary to carry off this waste heat amounts to about one third of the average daily freshwater run-off in the United States.[23] If our rivers, streams and oceans are to supply cooling water for power generation, existing species of fish and other plant and animal life face extermination via thermal pollution of their environment.[24] A partial solution to this problem lies in development of intermediate cooling stations such as cooling towers or reservoirs.

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[22] Ibid.

[23] Ibid.

[24] Fish cannot regulate body temperature. They must find water compatible with their body temperature or die.

The radioactive waste from nuclear power plants poses a serious poisoning hazard. The waste is dangerous to most plants and animals, and must be isolated in such a manner that it cannot possibly contaminate the environment. This requirement necessitates elaborate sealing and storing procedures. Simply burying radioactive waste in the ground is unacceptable. Radioactive materials can contaminate underground water supplies and their ultimate destination is impossible to predict. Unless the waste is properly sealed it may enter food and life cycles of plants and animals. Public concern over radioactive waste disposal has caused reevaluation of disposal techniques and will most certainly effect nuclear steam generating production costs.

The Atomic Energy Commission has requested $3.5 million to initiate development of an underground radioactive waste depository. The project called "Salt-Vault" is located at Lyons, Kansas. The depository, to be placed in underground salt beds, will eventually cost $25 million and cover one square mile.[25]

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[25] "A Nuclear Graveyard," Newsweek, March 29, 1971, p. 60.

CHAPTER V

MHD IN MONTANA

Comparative Advantages

Montana is one of the very few states which possess both favorable location and sufficient coal for a large-scale MHD power production industry. Montana has another important advantage, adequate water supply.

The coal reserves located in Montana and the contiguous states and Canadian provinces are of sufficient magnitude to support large power production facilities for hundreds of years (Figure 7). The United States Geologic Survey had estimated coal reserves exceeding 900 billion tons in Montana and Wyoming.[1] This was revised downward in 1949 and 1950 to 340 billion tons, two thirds of which was in Montana.[2] The present estimate of 222 billion tons of coal in Montana is based on core samplings from ninety percent of the known coal bearing strata, so it represents

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[1] U. S., Congress, Senate, Committee on Interior and Insular Affairs, Magnetohydrodynamics (MHD), Hearings, before the Subcommittee on Minerals, Materials, and Fuels, Senate, 91st Congress, 2nd session, February 23, 1970, p. 187.

[2] U. S., Department of the Interior, Bonneville Power Administration, Pacific Northwest Economic Base Study For Power Markets--Coal, 1965, p. 50.

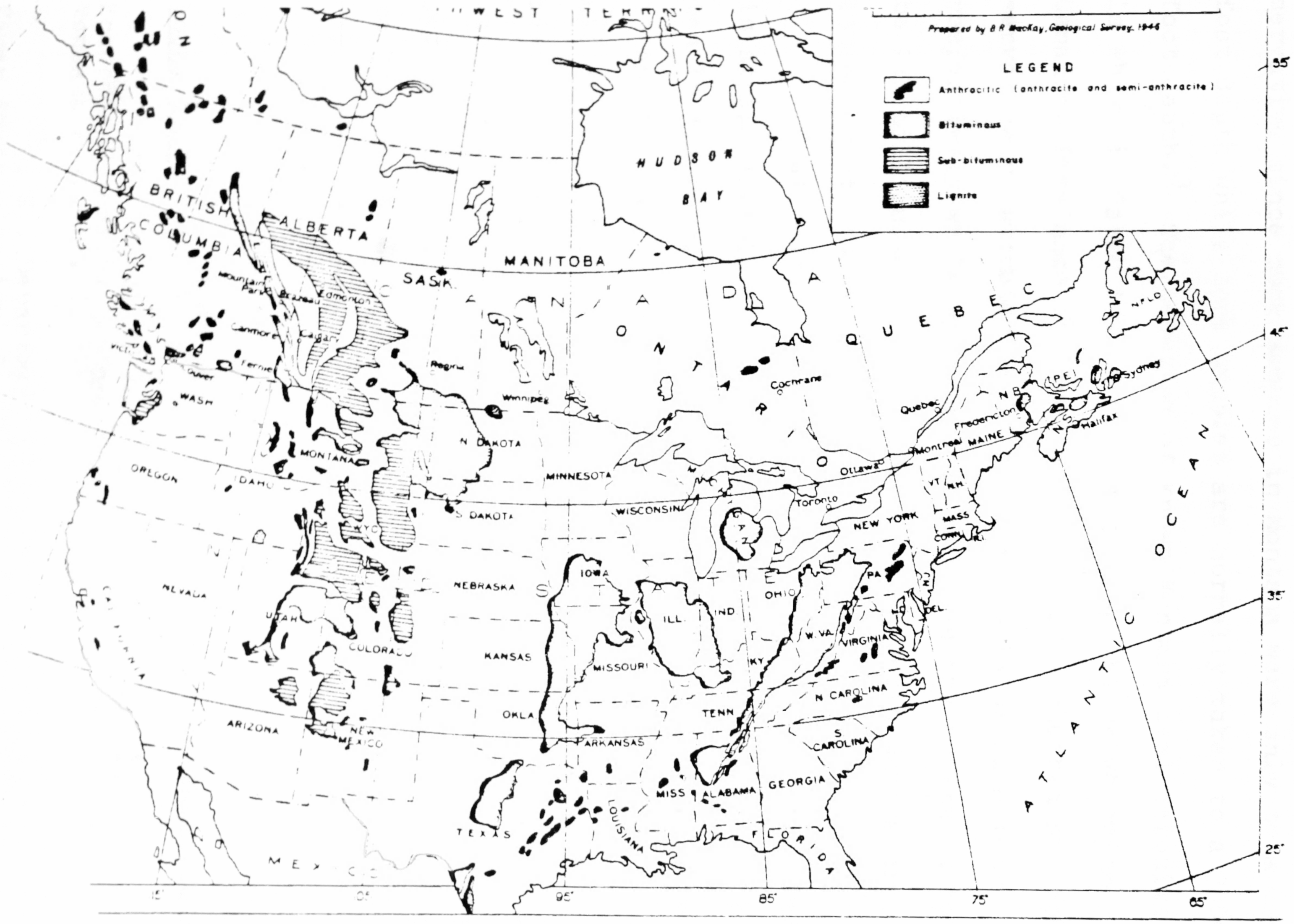

Fig. 7.--A map of coal deposits in North America.

a fairly accurate figure. It is, however, probably conservative since core samples in Montana were only to a 2000 foot depth while core samples are normally taken to a 3000 foot depth.[3] The location of known Montana coal deposits is shown in Table 10. Coal reserves in the neighboring Canadian Provinces of Alberta and British Columbia are conservatively estimated at 47 billion and 19 billion tons respectively while Wyoming coal reserves are estimated to be 121 billion tons.[4] Coal reserves in North Dakota are estimated at 350 billion tons.[5]

Coal prices are considerably reduced when the coal is strip mineable. Fifty percent of Montana's coal is located in Big Horn, Powder River and Rosebud counties. Between 13 and 17 billion tons of this is strip mineable coal.[6] The difference in prices between strip mined coal and shaft mined coal is considerable. In 1965 when most Montana coal was shaft mined, Western Montana coal sold at $3.75 to $4.93 per net ton f.o.b. This price resulted in fuel costs of 19.6 to 22.6 cents per million BTU f.o.b.[7] In 1969 the Peabody

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[3] Ibid.

[4] Ibid., p. 51.

[5] U. S., Department of the Interior, Minerals Yearbook, 1967, Vol. II, p. 617.

[6] University of Montana Bureau of Business and Economic Research, Montana Economic Study, Project No. Montana P-31, pt. 2, Vol. 1, p. 2.40.

[7] U. S., Department of the Interior, Bonneville Power Administration, Pacific Northwest Economic Base Study For Power Markets--Coal, 1965, p. 42.

Table 10

Estimated Original Coal Reserves in Montana, By County (In Millions of Short Tons)

County	Total
Big Horn	43,500.65
Blaine	39.73
Broadwater	5.66
Carbon	1,247.22
Carter	463.47
Cascade	435.12
Chouteau	1.48
Custer	4,877.71
Daniels	3,964.72
Dawson	11,110.49
Fallon	2,544.08
Fergus	342.94
Garfield	612.74
Glacier	33.36
Granite	23.00
Hill	76.55
Judith Basin	243.93
McCone	24,871.57
Meagher	.53
Missoula	19.70
Musselshell	3,471.79
Park	33.23
Phillips	3.50
Pondera	21.89
Powder River	43,418.17
Prairie	1,581.27
Richland	21,085.62
Roosevelt	4,164.23
Rosebud	38,883.88
Sheridan	5,763.82
Stillwater	12.67
Treasure	1,303.66
Valley	257.93
Wibaux	7,040.73
Yellowstone	590.20
	222,046.94

Source: U.S. Congress, Senate Committee on Interior and Insular Affairs, Mineral and Water Resources of Montana, Report of the U.S. Geological Survey in collaboration with Montana Bureau of Mines and Geology, Committee Print, 88th Congress, 1st Session (Washington, D.C.: U.S. Government Printing Office, 1963), p. 46.

Coal Company owning two to three billion tons of strip mineable coal in Montana and Wyoming estimated coal prices of 11.5 to 14 cents per million BTU delivered to generating plant.[8]

New unit construction coal trains have lowered coal transportation costs in North Dakota and Montana. Such transportation innovations can significantly effect fuel costs.[9]

Coal prices in the neighboring state of Wyoming were $2.04 per net ton f.o.b. or 10.3 cents per million BTU in 1965. Strip mineable Wyoming coal has been quoted as low as six cents per million BTU in 1969, and other cost estimates for Wyoming strip mineable coal varied between ten and fourteen cents per million BTU.[10]

Significant savings can result from lower transportation cost. The early railroads relied on coal for fuel, so

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[8] U.S., Congress, Senate, Committee on Interior and Insular Affairs, <u>Magnetohydrodynamics (MHD)</u>, before the Subcommittee on Minerals, Materials, and Fuels, Senate, 91st Congress, 2nd Session, February 23, 1970, p. 188.

[9] Montana Bureau of Mines and Geology, Directory of Mining Enterprises for 1969, (Butte, Montana: Montana College of Science and Technology, April, 1970), p. 49; New unit construction coal trains carrying coal from Montana to Minnesota and expected to reduce transportation costs 24% by 1973.

[10] U.S., Congress, Senate, Committee on Interior and Insular Affairs, <u>Magnetohydrodynamics (MHD)</u>, before the Subcommittee and Minerals, Materials, and Fuels, Senate, 91st Congress, 2nd Session, February 23, 1970, p. 187-189.

there are railroad arteries connecting most major coal bearing areas in the Northwest. There are operational railroad lines in proximity to all the large coal fields in Montana. When power plants are located in proximity to large coal fields and rail transportation costs are high, coal-slurry pipelines may present an economic transportation alternative. Estimated capital investment and operating costs for coal-slurry lines are listed in Table 11.

In summary there are sufficient fuel coal reserves in Montana and adjacent to Montana to support a large electric power generating industry. Fuel costs in the Northwest are lower than in other areas of the nation.[11] Reduced transportation costs resulting from proximity to the fuel reserves can substantially lower fuel costs and rail transportation is available. There are alternatives to rail transportation such as coal slurrys if the need should present itself.

Strategic Location

In February of 1968, the Department of the Interior published an extensive Steering Committee Report titled, "Transmission Study 190."[12] An interconnected high voltage

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[11] In 1967 the NCA National Average Coal price was 25.2 cents per million BTU.

[12] U.S., Department of the Interior, Bureau of Reclamation, Bonneville Power Administration, Southwestern Power Administration, Transmission Study 190, February, 1968.

Table 11

Estimated Capital Investment and Operating Costs for Coal-Slurry Pipelines

	6 million*			
	Distance, miles			
	250	500	750	1,000
Capital investment, millions of dollars				
Slurry preparation	10.78	10.78	10.78	10.78
Main pipeline	25.98	51.97	77.94	103.92
Pumping Stations	4.27	8.22	12.51	16.43
Terminal storage	2.35	2.35	2.35	2.35
General plant	1.21	2.10	2.90	3.66
Subtotal	44.59	75.42	106.48	137.14
Working capital	3.38	3.92	4.63	5.24
Total	47.97	79.34	111.11	142.38
Operating cost dollars per ton				
Slurry preparation and piping	.61	.71	.81	.91
Slurry handling	.25	.25	.25	.25
Moisture penalty	.15	.20	.25	.30
Capital charges	1.28	2.12	2.96	3.80
Credit	(.45)	(.45)	(.45)	(.45)
Total	1.84	2.83	3.82	4.81

Source: U.S. Department of the Interior, Bonneville Power Administration, Pacific Northwest Economic Base Study For Power Markets--Coal, 1965.

*Annual quantity of coal, (tons per year)

Table 11--Continued

9 million*				15 million*			
Distance, miles				Distance, miles			
250	500	750	1,000	250	500	750	1,000
15.87	15.87	15.87	15.87	25.95	25.95	25.95	25.95
31.46	62.93	94.39	125.85	41.01	82.01	123.02	164.02
5.33	11.07	16.49	22.25	6.78	13.92	20.73	27.59
3.00	3.00	3.00	3.00	4.17	4.17	4.17	4.17
1.54	2.68	3.71	4.67	2.14	3.73	5.16	6.49
57.20	95.55	133.46	171.64	80.05	129.78	179.03	228.22
4.24	5.00	5.77	6.53	5.95	6.95	7.93	8.91
61.44	100.55	139.23	178.17	86.00	136.73	186.96	237.13
.59	.67	.75	.82	.57	.63	.69	.75
.25	.25	.25	.25	.25	.25	.25	.25
.15	.20	.25	.30	.15	.20	.25	.30
1.09	1.79	2.48	3.17	.92	1.46	1.99	2.53
(.45)	(.45)	(.45)	(.45)	(.45)	(.45)	(.45)	(.45)
1.63	2.46	3.28	4.09	1.44	2.09	2.73	3.38

transmission system, tying all the western power-load centers together would permit optiminum use of existing generating capacity and provide economic benefits to all users. Analysis of electric power requirements for four regions of the United States (Pacific Northwest, North Central, Central and South Central) was made. By 1975 there will exist significant electric power consumption diversities between these regions. These diversities will result from seasonal and time zone power demand variations.[13] For example, in the summer of 1975 the Pacific Northwest region will require 1600 MW more capacity than the North Central states but in the winter of the same year, the North Central states will require 1600 MW more capacity than the Pacific Northwest. This is a 1600 MW seasonal diversity. With a high voltage transmission system connecting the two regions, only a single area would have to increase generating capacity to meet the power needs of both areas. If a Montana power generation system were connected to this transmission system, they could sell power to the North Central region in the winter and an equal volume to the Pacific Northwest in the summer. The transmission system would optimize capacity on a year round basis. This more efficient use of capacity would result in economic benefits to consumers in both the Pacific Northwest and the North Central regions and of course to the company selling the

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[13] Ibid., p. 7.

power. The expected seasonal diversities between all four load regions analyzed in Study 190 is illustrated in Figures 8, 9 and 10.[14]

The example cited above is just one power situation. When power demands between regions and even within regions, are analyzed collectively, additional diversities are uncovered. One important basic fact emerges. It is more economical to generate power in a few regions and transmit it to other regions as needed, than for each individual region to develop independent generating capabilities. Twelve proposed high voltage transmission systems for the Western United States are shown in Figures 11, 12, 13 and 14.

The initial effect of a power intertie connecting all the load centers would be a reduction in the now expected need for new generating capacity. Existing capacity would instead be used more efficiently. Efficient use of existing capacity, however, will only delay the need for new generating equipment. A large power intertie not only permits more efficient use of existing capacity, but it serves as a vast electric power market place. Regions with idle capacity can sell power to regions which need power. Regions which need power for emergencies will have reserve power available. In addition, low cost production regions can develop power

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[14] Diversity figures are based on Federal Power Commission power estimates for 1975 and 1980.

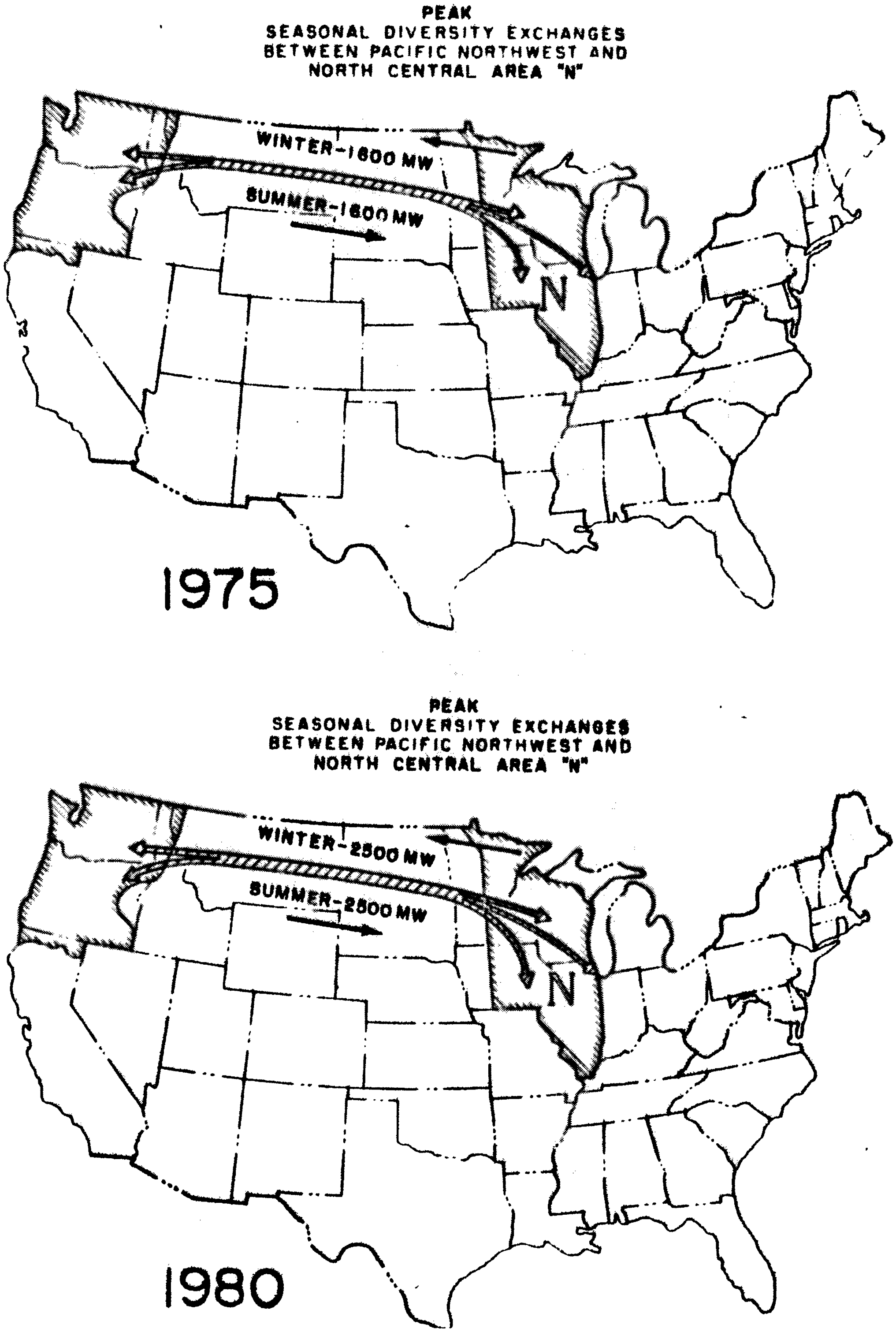


Fig. 8.--Expected power diversities between the Pacific Northwest and North Central load regions for 1975 and 1980.

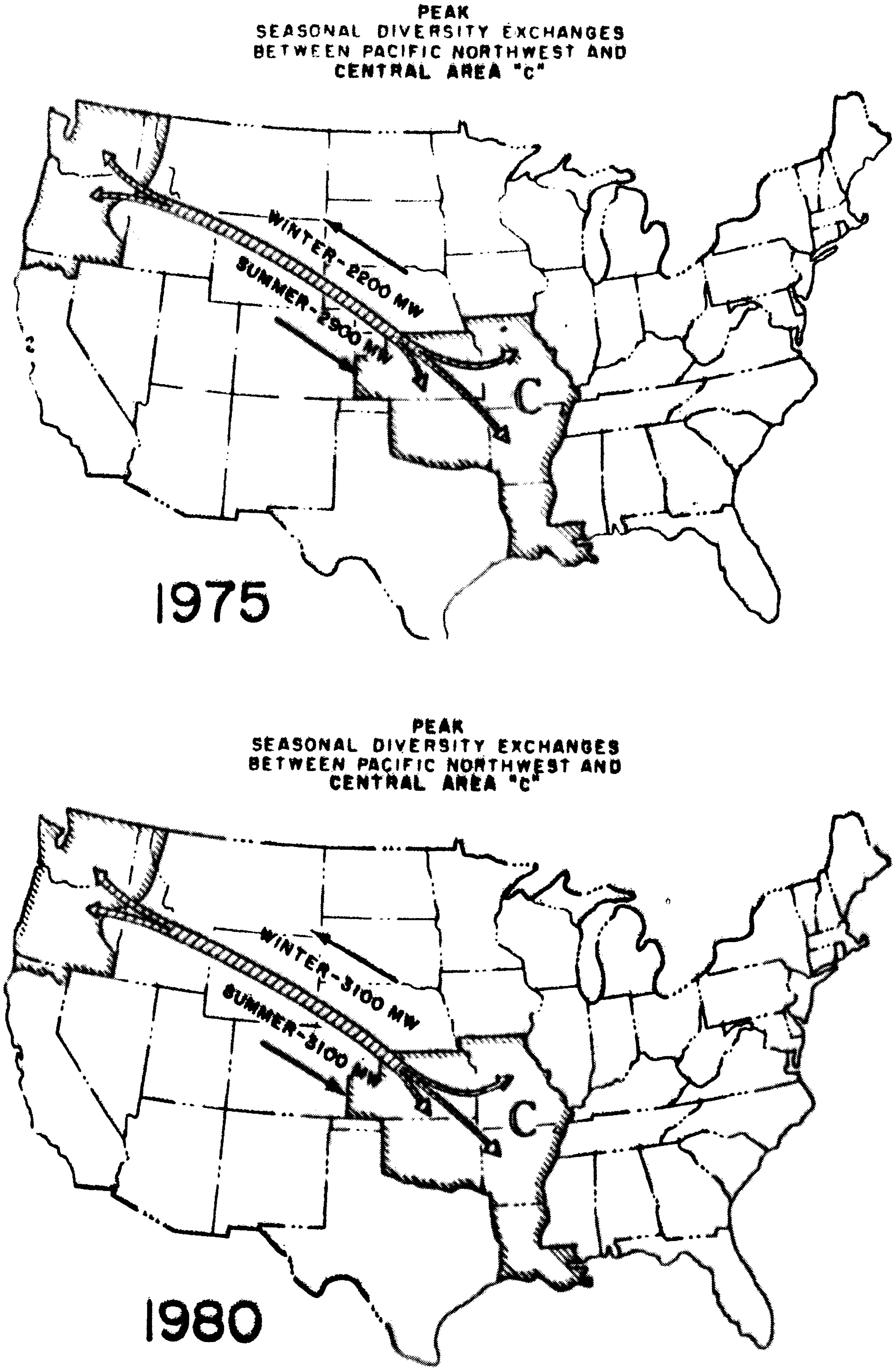


Fig. 9.--Expected power diversities between the Pacific Northwest and Central load regions for 1975 and 1980.

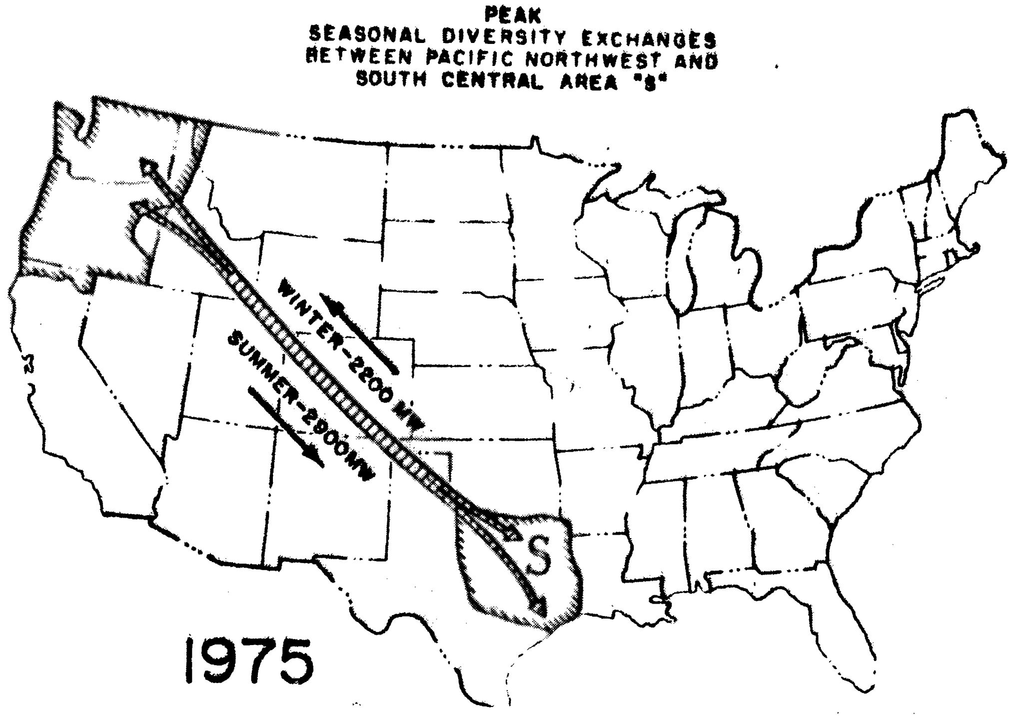
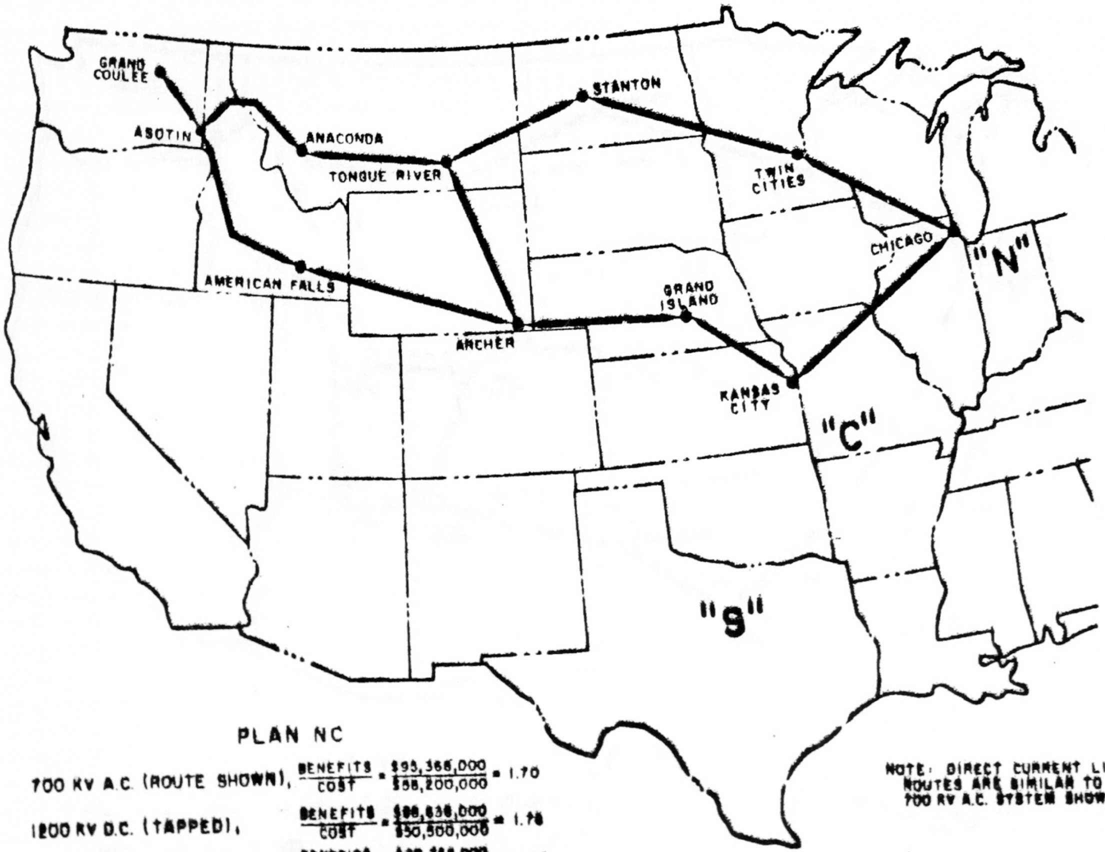


Fig. 10.--Expected power diversities between the Pacific Northwest and South Central load regions for 1975 and 1980.



PLAN NC

700 KV A.C. (ROUTE SHOWN), $\frac{\text{BENEFITS}}{\text{COST}} = \frac{\$95,366,000}{\$56,200,000} = 1.70$

1200 KV D.C. (TAPPED), $\frac{\text{BENEFITS}}{\text{COST}} = \frac{\$88,836,000}{\$50,500,000} = 1.76$

1200 KV D.C. (UNTAPPED), $\frac{\text{BENEFITS}}{\text{COST}} = \frac{\$70,745,000}{\$36,900,000} = 1.92$

NOTE: DIRECT CURRENT LINE ROUTES ARE SIMILAR TO THE 700 KV A.C. SYSTEM SHOWN.

Fig. 11.--Proposed high voltage transmission systems connecting the North, Central, and Pacific Northwest power load regions.

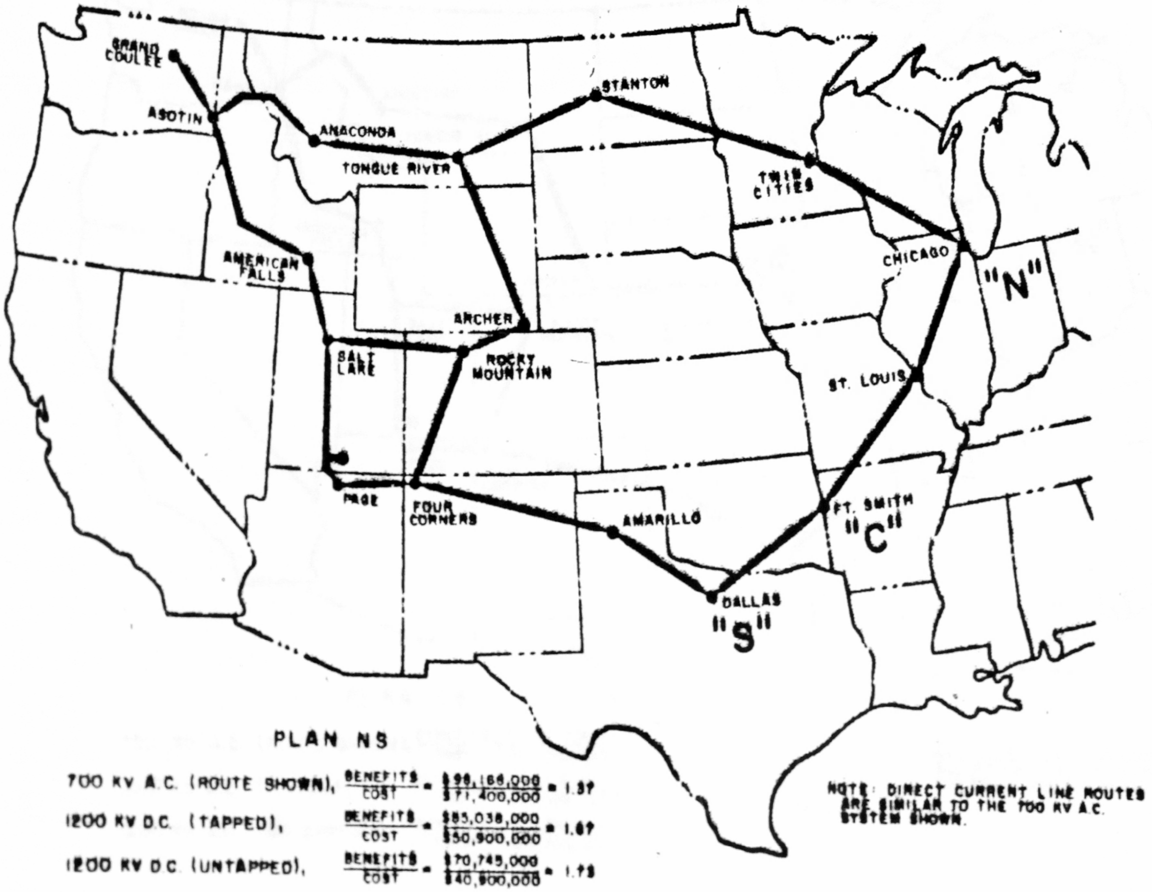


Fig. 12.--Proposed high voltage transmission systems connecting the North, Central, South, and Pacific Northwest power load regions.

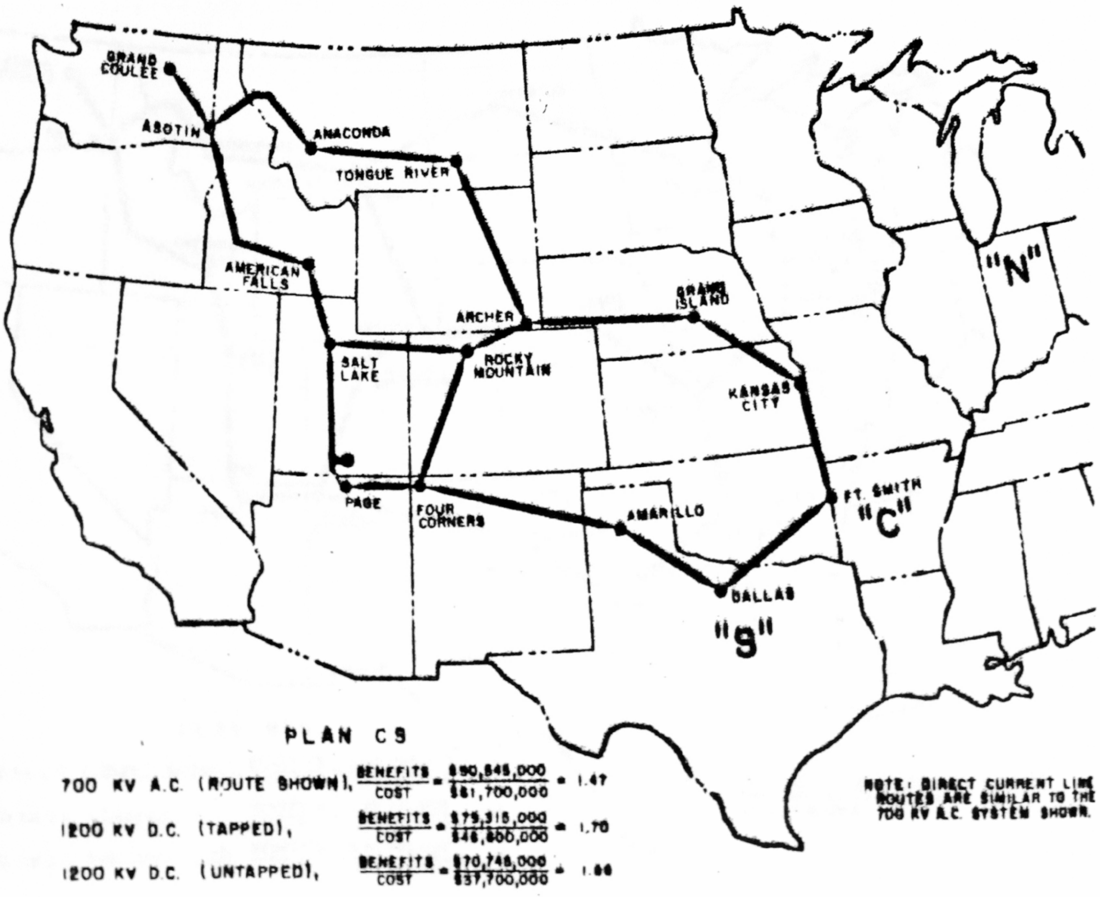


Fig. 13.--Proposed high voltage transmission systems connecting the Central, South, and Pacific Northwest power load regions.

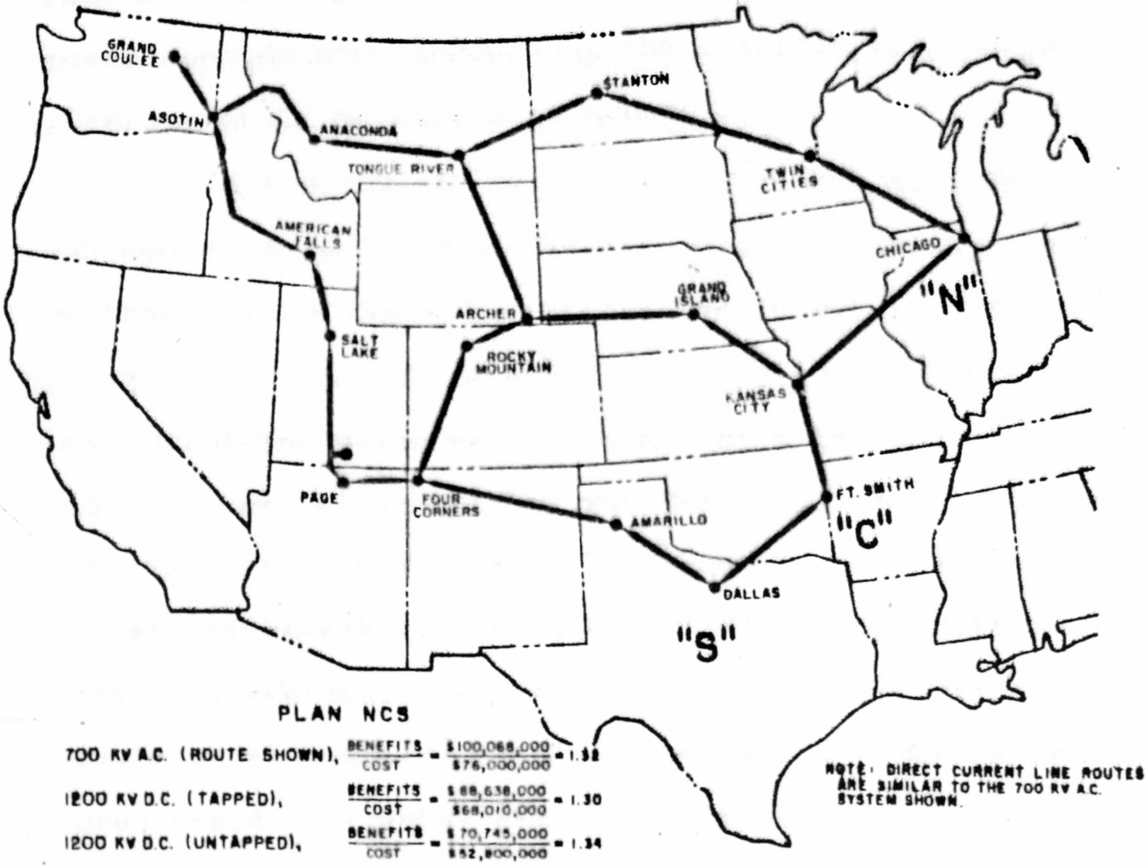


Fig. 14.--Proposed high voltage transmission systems connecting the North, Central, South, and Pacific Northwest power load regions.

generation industries to supply intertie users. Montana is just such a place. By 1980 it would be economical to establish a 1600 MW generating plant in Montana with the expressed objective of maintaining an electrical energy supply for the Pacific Northwest and the West Central load regions.[15] As power demands grew throughout the intertie system, generating capacity could be increased accordingly.

A proposal submitted by Ken Holem and Associates (Consultants to the Western Intertie Task Force), suggested a 3200 MW capacity installation located in Wyoming or Montana composed of four 800 MW generators, two supplying power east and two supplying power west. Total estimated cost including an eight percent fixed charge, was $450 million with transmission costs of $300 million.[16] Eight of the twelve proposed interties illustrate high voltage DC interconnectivity. Substantial savings could be realized by MHD power production centers feeding a DC transmission system. The MHD generator produces direct current. Expensive conversion equipment is required to convert the DC to AC current. A large MHD generating plant feeding a DC transmission system directly would

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[15] U.S., Department of the Interior, Bureau of Reclamation, Bonneville Power Administration Southwestern Power Administration, <u>Transmission Study 190</u>, February 1968, p. 15.

[16] U.S., Congress, Senate, Committee on Interior and Insular Affairs, <u>Magnetohydrodynamics (MHD)</u>, before the Subcommittee on Minerals, Materials, and Fuels, Senate, 91st Congress, 2nd Session, February 23, 1970, p. 186.

avoid the need for DC to AC conversion equipment at plant site thereby reducing production costs.

An electric intertie with high voltage transmission lines passing through Montana has significant economic benefits for the entire West Central United States. A developing power market will exist within the area served by the suggested transmission system and a power generation industry located in Montana, could supply this system. MHD power generation would require less fuel and produce less atmospheric and thermal pollution than other thermal generation plants. MHD would have an additional cost advantage over other power production methods if a DC transmission intertie were developed instead of AC.

Water costs are an important factor in electric power generating site selection.[17] The Bureau of Reclamation could supply industrial water from the Yellowtail Dam on the Big Horn River and there are under consideration plans to enlarge the dam and reservoir on the Tongue River. The Bureau of Reclamation is also completing plans for its Morehead Dam on the Powder River. These developments indicate that water can be made available for industrial development in Southern Montana if required.

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[17] Ibid., p. 188.

Economic Advantages Versus Environmental Costs

MHD in Montana could have several economic advantages over other power production methods.

Capital costs for MHD are expected to be less than capital costs for any other power generation methods. At $95 to $112 per KW installed capacity MHD has the lowest plant cost.

Fuel costs for an MHD installation in Montana would be less than fuel costs for existing conventional and nuclear steam generating plants. The increased thermal efficiency of MHD (approaching 60%) means that when compared with conventional steam generating plants (efficiency 42% maximum), the MHD unit can produce the same amount of power as the conventional unit, using thirty percent less fuel. It presently requires approximately five million tons of coal annually to maintain a 1000 MW generating capacity.[18] A thirty percent fuel savings would reduce this figure to 3.5 million tons. The Office of Science and Technology estimated that early adoption of MHD power generation facilities could result in national fuel savings of $11 billion by the year 2000.[19] Nuclear fuel costs, may be competitive and eventually less expensive than MHD fuel costs but these savings may only be realized after completion of a multi-billion dollar research and development effort.

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[18] Ibid.

[19] Ibid., p. 125.

MHD can produce power with less harmful effects on the environment than most other power generation methods. One outstanding feature of MHD is that effluent gases must be treated for seed removal, and removing pollutants can be accomplished at the same time with relatively little extra cost. The cost of removing pollutants from MHD gases is therefore a normal part of plant costs, operating expenses and maintenance expenses.

The most serious environmental problem which could result from MHD development in Montana would be land spoilage from coal mining operations. Coal strip-mining accounts for forty-one percent of the land disturbed by surface mining in the United States. In Montana coal strip-mining is still in the development stage. In 1965 there were three strip mines producing 300,000 net tons annually.[20] By 1970 coal strip-mining increased tenfold to three million net tons annually.[21] A 3000 MW MHD facility would require at least 10.5 million net tons annually of strip mined coal, a further 350 percent increase. Reclaiming strip mined topography must therefore be mandatory if Montana is to retain the state's natural beauty.

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[20] U.S., Department of the Interior, Bureau of Reclamation, Surface Mining and Our Environment, 1967, p. 114.

[21] In 1968 Minnesota Power and Light Company contracted for annual purchases of 2 million tons of low sulfur coal from Big Sky Mine in Colstrip, Montana.

The record of land reclamation in Montana is not enviable. As of January 1965, there were 26,920 acres of land disturbed by strip and surface mining in Montana. Seventy-three percent of that acreage still required reclamation.[22] Strip mined coal in the West North Central United States disturbes land at the rate of one acre per 26,000 tons of coal produced.[23] Additional strip-mining operation to support an MHD plant requiring 10.5 million tons of coal per year would disturb 400 more acres annually.

The costs to reclaim land disturbed by coal strip and surface mining in the West North Central United States averages $91 per acre for land completely reclaimed and $126 per acre for land partially reclaimed.[24] Approximate reclamation costs for strip mined lignite in Montana varied from $0.013 per ton to $0.34 per ton depending upon the reclamation cost per acre. Reclamation costs in Montana are among the lowest in the nation. Only Alaska and Wyoming, reclaimed land at less cost than Montana.[25] The reason for low reclamation costs in Montana, Wyoming and Alaska is the high coal productivity per acre in these states (Table 12). Lower

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[22] U.S., Department of the Interior Bureau of Reclamation, Surface Mining and Our Environment, 1967, pp. 110-111.

[23] Ibid., p. 112.

[24] Ibid., p. 113.

[25] Ibid., p. 114.

Table 12

Approximate Reclamation Cost Per Ton of Coal Mined by Stripping in 2 States, in 1960

State	Calculated Production Per Acre Mined[a]	Cost Per Ton at Reclamation Costs of--					
		$300 per Acre	$400 per Acre	$500 per Acre	$600 per Acre	$700 per Acre	$800 per Acre
Montana	23,290	.013	.017	.021	.026	.030	.034
Wyoming	66,096	.005	.006	.008	.009	.011	.012
U.S. Average	7,344	.041	.054	.068	.082	.095	.109

[a] Based on specific gravities of 1.32 = 82.64 lb. per cu. ft., or 1,440 tons of bituminous coal per acre foot and 1.29 = 80.50 lb. per cu. ft., or 1,403 tons of lignite per acre foot, at assumed 80 percent rate of recovery X the State average-thickness of seam (ft.) mined in 1960.

Source: U. S. Department of the Interior, Bureau of Reclamation, Surface Mining and Our Environment, 1967.

reclamation costs in Montana support the desirability of a large power production facility in Montana. Not only is the fuel less expensive, but reclamation costs are also less.

In 1968 the acreage consumed by strip-mining in Colstrip, Montana was twenty-two acres per million tons of coal or 45,500 tons per acre.[26] The resulting pit and spoil banks occupy a somewhat larger area. The figures in Table 12 are based on coal productivity of 23,000 tons per acre. The increased productivity at Colstrip indicates a further reduction in reclamation costs.

A second environmental problem of MHD and one faced by other industries is how to dispose of acids produced from cleaning flue gases. Nitric and sulfuric acid have some commercial value at present. An argument often presented in favor of forcing generating plants to lower sulfur and nitrogen oxide emissions is that the acids produced by the cleaning process have commercial value and will offset pollution control costs. The market for sulfuric and nitric acid may become completely saturated as more industries produce acids as a by-product of pollution control. In 1969 nitric acid production in the United States was approximately 6.3 million short tons and sulfuric acid production was 29 thousand short tons. Both figures represented no increase from the previous

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[26] U.S., Department of the Interior, Bureau of Mines, Disposal Solid Wastes From Coal Mining in Washington, Oregon and Montana, 1969, p. 37.

year, in fact nitric acid production was less.[27] If all the sulfur presently entering our atmosphere from fossil fuel burners could be recovered, the amount of sulfur collected would exceed national sulfur production by four million tons per year. If the commercial value of nitrogen and sulfur oxides deteriorates from a flooded market, disposal may present a future problem. Acid cannot be dumped into streams any longer or poured into the ground.[28] There are three alternatives which appear likely. (1) New markets must be developed for the acid by-product, (2) New products must be manufactured from the acid by-product, i.e., nitrates from nitric acid, sulfur from sulfuric acid, and (3) The acid must be secured and stored in an area where it will not harm the environment until such a time as profitable use can be made of it (a problem presently facing nuclear power plants with radio-active waste).

How Montana Can Develop an MHD Industry

A developed MHD power generation system in Montana could aid significantly in meeting the power demands of the Pacific Northwest and the Central Northwest states. But an MHD power generation system would be better for Montana and more readily accepted if it could provide tangible benefits

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[27] U.S., Department of Commerce, Statistical Abstract of the United States, 1970, Table 1146, p. 718.

[28] Much of the 136 miles of Montana streams already polluted by mining operation is a result of mine acid pollution.

other than cheap power. The question which is likely to arise from state residents is "What economic benefits are available to Montana and should Montana not receive some extra compensation for providing a service to the rest of the country?" With forsight and determination it may very well be possible to develop in the host state of an MHD power generation system, a multi-product industry. This alternative is especially attractive in a state such as Montana where the job market lags the labor market resulting in a high immigration rate among young wage earners.[29]

MHD capital costs should be less for char-fired plants than coal-fired plants. It is feasible to establish a coal reduction facility using char to fire an MHD system and market the by-products of the char reduction process. An investigation into this possibility has been conducted with western coals and preliminary tests show that char production from western coals is economically feasible. It was estimated that a char production facility could yield a return on investment of seventeen percent with a payback time of 3.7 years. Two other western coals tested yielded estimated returns on investment of 12.7 percent and 3.3 percent.[30]

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[29] University of Montana Bureau of Business and Economic Research, Montana Economic Study, Project No. Montana P-31, pt. 1, Vol. 2, p. 2.23-2.24, 2.43.

[30] U.S., Department of the Interior, Office of Coal Research, The Charing of Western Coals, 1969, p. 27.

Expansion of metalurgical industries in Montana at an MHD industrial center is also a possibility, especially metalurgical processes requiring direct current. Montana is rich in many ores and a central metal production center may have definite economic advantages.

A chemical production facility might also be developed at an MHD industrial center. Acids will be readily available and sulfur products could be manufactured. By-products from the char reduction facility including creosote, hydrogen gas, and methane, could be used to produce some chemicals.

An MHD center could also include a refinery complex. The proximity of cheap electric power, water and a heat source could attract many such industries.

The flow diagram of a possible multi-product MHD plant is shown in Figure 15. The feasibility of a multi-product MHD plant was suggested to the Mid-West Electric Consumers Association in an independent research report submitted by Burns and Roe, Inc., Oradell, New Jersey.[31]

A multi-purpose MHD plant in Montana would be advantageous to the nation and the state. More efficient use would be made of natural resources. Sufficient power would be available to meet regional as well as local needs, and industrial development would ultimately lead to accelerated economic growth in Montana.

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[31] U.S., Congress, Senate, Committee on Interior and Insular Affairs, Magnetohydrodynamics (MHD) Hearings, before the Subcommittee on Mineral, Material, and Fuels, Senate, 91st Congress, 2nd Session, February 23, 1970, p. 145.

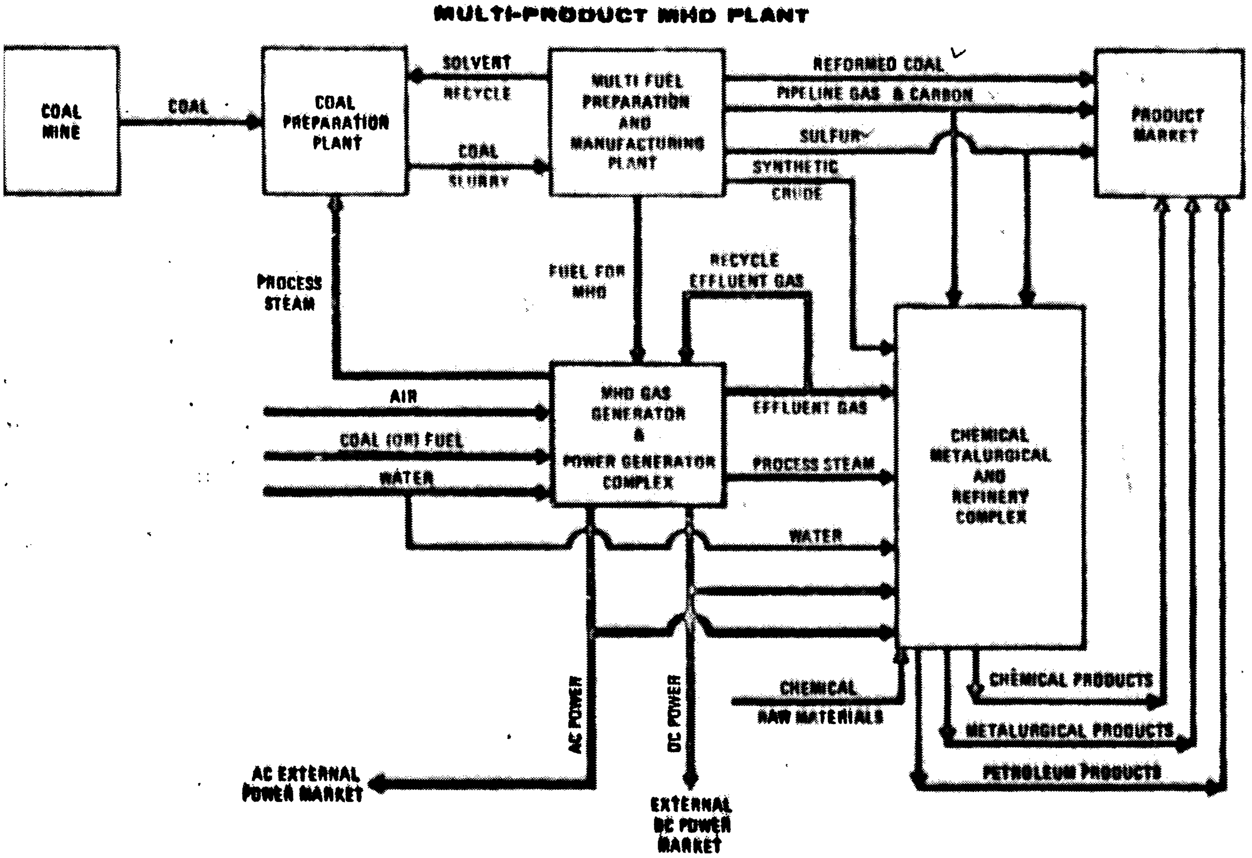

Fig. 15.--Flow chart of an MHD multi-product plant.

CHAPTER VI

CONCLUSION

The Need for MHD

Large central power stations supplying demand centers via high voltage transmission interties offer an economical method for supplying the power requirements of future decades. Electric power is an extremely important factor effecting national growth and will be needed in ever increasing quantities. Inexpensive power has been produced in the past but only with extensive environmental damage. As a growing health hazard motivates our concerned society toward evnironmental controls, the time for a "show-down" is rapidly approaching. We must as a nation develop power production methods which satisfy growth needs without destroying our environment in the process. If improved methods are not developed the society will be faced with two alternatives. Either growth will be accomplished at the cost of a deteriorating environment or growth will be foregone to preserve the environment. The need for power production methods which will meet future demands while simultaneously meeting environmental standards is therefore apparent. If this method is cost competitive with existing power generation methods, then there exists a practical solution to our nation's power malaise. Magnetohydrodynamics (MHD) is a power production method which potentially can satisfy the prerequisites demanded of future power generation methods. Comparing MHD with hydroelectric power, conventional steam power, and nuclear steam power (Table 13) reveals that with plant costs of $95 to $112 per KW capacity, and annual production costs of 1.74 mills per KWH, MHD is economically competitive with present power generating methods. The estimated development costs of $50 to $100 million for MHD are small when compared to the $2 billion development cost of first generation nuclear plants and the additional $4 billion development costs expected for nuclear fast-breeder reactors. In addition, MHD plants built by 1980 could save over $11 billion in fuel costs by the year 2000, in essence, paying for themselves several times over. MHD presents an attractive alternative.

Better but higher cost estimates resulting in new plant reductions, cast serious doubt on projected nuclear plant development. Although nuclear development is continuing, new problems arising from waste disposal and thermal pollution further inhibit nuclear development. Realization that nuclear power generation has serious disadvantages suggests that MHD could very well fill the developing technological gap.

Table 13

A Comparison of MHD With Present Power Sources

	Plant Cost Dollar/KW Capacity	Production Cost Less Fuel Mills/KWH	Fuel Cost Mills/KWH
MHD	95 to 112	.40	1.34
Hydroelectric	243	.53	N/A
Conventional Steam	115	.59	2.54
Nuclear Steam	210	1.42	2.53*

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*Development of the fast-breeder reactor could substantially reduce fuel costs.

Table 13--Continued

Annual Production Cost Mills/KWH	Thermal Efficiency (Percent)	Environmental Aspects
1.74	50 - 60	1. Requires extensive mining 2. Pollutant removed from flue 3. Requires least cooling water 4. Reduces coal resources
.53	N/A	1. Aids flood control 2. Causes scenic pollution 3. Effects fish ecology
3.13	42	1. Serious air pollution 2. Requires extensive mining 3. Reduces coal resources 4. Requires cooling water
5.37	33	1. Severe thermal pollution 2. Radioactive waste dangerous 3. Reduces uranium resources

Montana's Place in MHD Development

With growing seasonal power diversities between the Pacific Northwest and the Central United States as well as daily power diversities, Montana is ideally situated to serve as a power supply and distribution center for these areas. By 1980 Montana could market 1600 megawatts of electricity on a continuous basis to these load centers.

The extraordinary coal deposits located in Montana and neighboring territories could provide fuel to a Montana based power industry for several hundred years. Significant quantities of this coal (15 to 17 billion tons in Montana alone) are strip mineable reserves. Strip mining reduces coal costs considerably. Estimated coal costs in the Wyoming-Montana area are as low as eleven to fourteen cents per million BTU delivered, compared to the national average of 25.2 cents per million BTU.

An industrial complex designed around an MHD power production center could help reverse the emigration of young Montanans by providing a variety of employment.

Montana therefore exists as an ideal site for a future power generation industry. MHD once fully developed, could be the technological basis for a large power production industry. MHD can be cost competitive, more efficient and less dangerous to the environment than existing power production techniques.

Important Questions for Future Research

Industrial development per se is not a desirable goal for may Montanans. The state's natural beauty and its vast "unspoiled" territories motivate many residents to protect the status quo. The question, "How much resistance will there be to industrial development?" is an important one.

Power interties throughout the Western United States must be developed before a large Montana MHD power industry can be developed. The ability of regional power groups to combine resources and develop necessary intertie systems should be analyzed.

Recommendations

It is recommended that Montana's political and industrial leaders strive for accelerated MHD development with the ultimate objective being on MHD power industry in Montana.

The development of an industrial complex built around an MHD power facility should be explored with emphasis on industries requiring large volumes of low-cost power.

It is suggested that a preliminary MHD site selection be made. An MHD facility near strip mineable coal reserves, near a natural water supply and located along proposed intertie routes is suggested. The Tongue River Reservoir area in Southern Montana is suggested as a possible MHD plant site.

The inter-regional power administrations throughout the Western United States should combine forces to establish a high voltage intertie system as soon as possible and preliminary commitments to supply power should be established at that time.

APPENDIX I

Table 14

Electric Energy Production And Installed Generating Capacity: 1940 to 1969

Year	Production (Billion KWH)	Installed Capacity (Million KW)	Coal Fired (Percent)
1940	180	51	54.6
1945	271	63	51.7
1950	389	83	47.1
1955	629	131	55.1
1960	842	186	53.6
1965	1158	255	54.5
1968	1436	310	52.5
1969	1552	332	50.0

Source: Federal Power Commission; press release No. 16634.

Note: Includes non-utility power generation statistics.

Table 15

Per Capita Power Consumption

Year	(A) Electric Power Production Billion KWH	(B) Population Millions	(A ÷ B) Per Capita Consumption KWH/Year Per Person
1940	180	132.6	1357
1945	271	140.5	1928
1950	389	152.3	2554
1955	629	165.9	3791
1960	842	180.7	4659
1965	1158	194.6	5950
1970	1627	205.0	7936

Source: Statistical Abstract of the United States 1970, U. S. Department of Commerce, p. 6, 507.

APPENDIX II

Detail Discussion of MHD Components

Fuel--The fuel used in MHD must possess certain basic characteristics: (1) The temperatures of combustion must sustain ionization throughout the power production phase. (2) The resultant ionized gases must exhibit desired electrical properties when passed through a magnetic field. Coal and char are good fuels for the MHD process. First, they can sustain high temperature combustion; next, their chemical components provide ions with desirable electrical properties. Some Western coals contain seed material already in the coal, and less artificial seeding is required.

Preprocessed (reduced) coal is called char. Char has several characteristics which make it more desirable than coal. Char produces a cleaner flame, higher combustion temperatures, and better ionization characteristics than coal.[1] Char can be manufactured at the MHD plant site. Some by-products of the reduction of coal have application in the MHD process while others are marketable.

Montana contains ample coal deposits suitable for MHD fuel.

Burner--The combustion chamber or burner is where fuel and air combine in the burning process. The temperatures and

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[1] U. S., Department of the Interior, Office of Coal Research, Study of MHD Power System Burning Char with Oxygen. February, 1970, pp. 12-13.

gases resulting from combustion are critical to ionization. For MHD to be effective, temperatures approaching 5000°F must be achieved in the combustion chamber. To obtain these temperatures the air coming into the combustion chamber must be preheated to 3100°F.[2]

A 2-Stage Cyclone type furnace (Figure 16) appears a reasonable choice based on current knowledge.[3] A 2-stage cyclone furnace permits slag to be drawn off early in the combustion process, thus reducing fly ash.

The first stage mixes air and fuel for low temperature incomplete combustion. These conditions permit liquid slag to form on the floor of the first stage. The non-combustible impurities in coal are thereby removed early in the MHD cycle so they cannot contaminate the plasma with corrosive and ablative matter. Eighty-five percent of the ash from burning coal can be removed in the first stage and this number can be increased to ninety-four percent by a special refiring process. Over seventy percent of total fuel energy is introduced in the first stage.

Temperatures are raised substantially in the second stage where the remaining thirty percent of total fuel energy

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[2] U.S., Congress, Senate, Committee on Interior and Insular Affairs, Magnetohydrodynamics (MHD). Hearings before a subcommittee on Minerals, Materials, and Fuels, Senate, 91st Cong., 1st sess., December 18, 1969, p. 91.

[3] U.S., Department of the Interior Office of Coal Research, Feasibility Study of Coal Burning MHD Generation, February, 1966, Vol. II, p. 130.

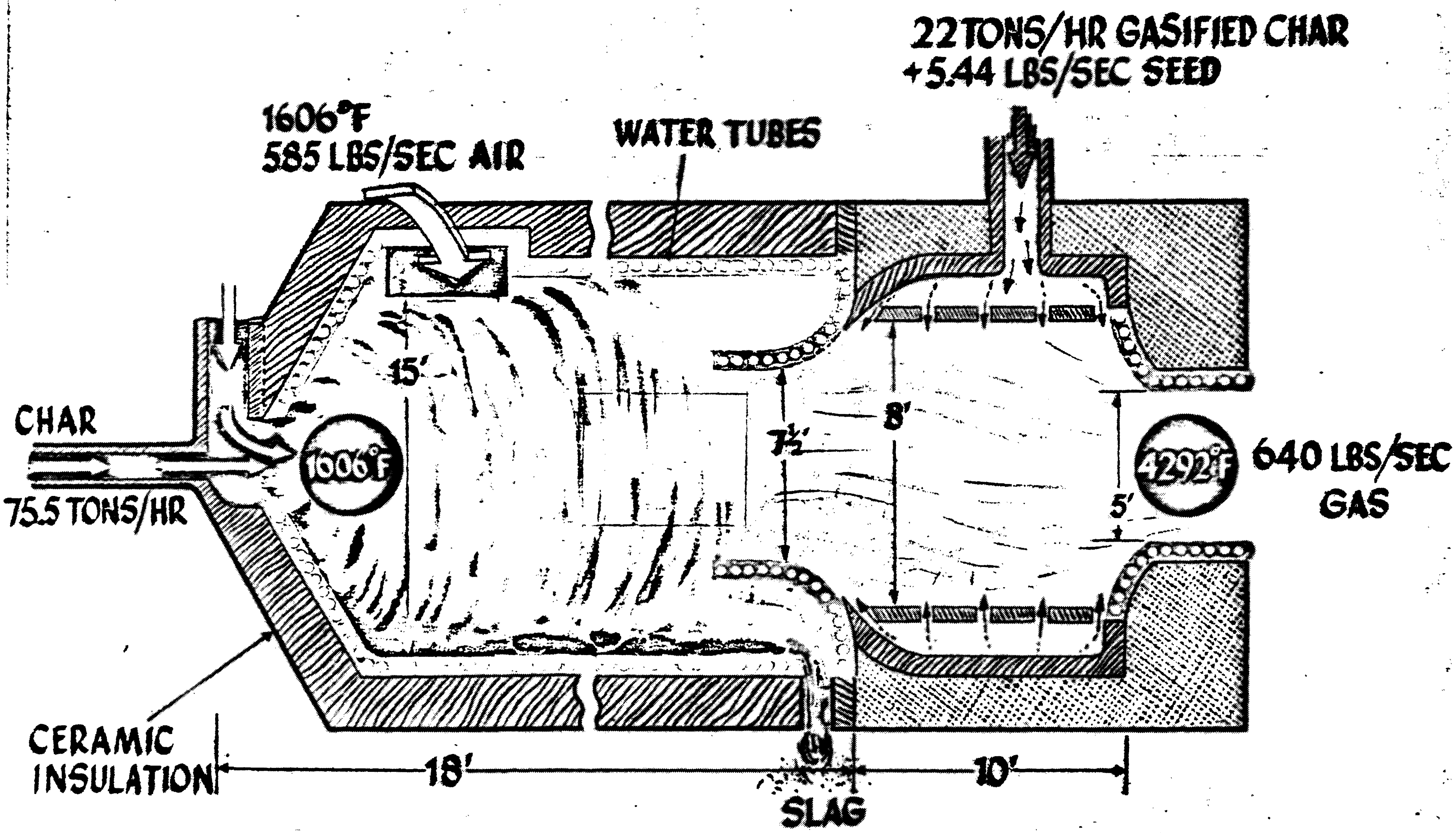

Fig. 16.--A 2-stage cyclone type furnace.

is added. These elevated temperatures permit ionization to occur. Seed material introduced into stage two ionizes instantly and as highly conductive plasma is developed the plasma exits stage two of the cyclone furnace through an expansion nozzle which accelerates the plasma into the MHD generator.

There are two ways to use coal with cyclone furnaces. The first method involves reducing coal to char and burning the char in stage one. Volatile gases from the reduction process are next fed into stage two. A second method involves burning raw coal in stage one and gasifying another portion of coal to form coal gas to burn in stage two.[4]

Regardless of the method used, an efficient combustion chamber must perform two tasks. First it must produce a 5000°F plasma and second, it must remove waste products (slag) before they vaporize and contaminate the plasma.

Seeding and Seed Recovery--The ionized gas created by burning coal in air is not conductive enough for efficient MHD power generation. The electrical properties of the plasma must be upgraded by adding metallic ions. This process is called seeding. When alkali metals such as cesium or potassium are injected into the combustion chamber the high temperatures ionize them. The metal ions enter the plasma, giving it the desired electrical conductivity.

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[4] Ibid., p. 151.

Seed may be introduced with the fuel before combustion, during combustion, or just after combustion.

Seed metals are expensive, cesium costs between \$1.40 and \$2.40 per pound and potassium costs \$0.15 per pound.[5] It is uneconomical to allow these metals to go up the stack after passing through the MHD generator, thus seed recovery and recycle is desirable.

Seed recovery involves extracting seed from the modified plasma after it passes through the power generation phase. Cesium is the most desirable seed presently available, but it is very costly. Cesium recovery must be at least 99.5 percent to be economical. Present electrostatic precipitation methods remove only 97 percent of solid cesium particulate matter from flue gas. A seed recovery method which shows promise is dry electrostatic separation followed by wet processing. (Air pollutants may also be removed during this process.)

The effluent gas from the power plant is passed through an electrostatic precipitator which removes most solid seed and ash. The seed exists as part of a water soluble sulfate or as part of the insoluble ash. The sulfate and ash are mixed with water to remove the water soluble sulfates. The seed remaining with the ash is reintroduced into the combustion chamber where heat separates the seed

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[5] Ibid., Vol. III, p. 2-2.

from the ash. The seed vaporizes, becoming part of the plasma and the ash liquifies entering the slag. The seed dissolved in water is precipitated out and reintroduced directly into the combustion chamber.[6]

Some coals have alkali metals already in them. This natural seed, however, often enters the slag before entering the plasma. If the percentage of seed in slag is high enough, the slag may be recycled through the furnace to extract this seed.

MHD Generator--Electricity is produced in the MHD generator. There are three major pieces of equipment in the generator: (1) a superconducting magnet, (2) the MHD channel, and (3) power collection equipment.

The MHD channel is surrounded by a large superconducting magnet. The magnet creates a powerful magnetic field in the channel. Plasma in the channel flows through the magnetic field and free electrons (cations) move toward one of the magnetic poles while positively charged ions (anions) move toward the opposite one. An electrical imbalance is created in the MHD channel. Electrodes placed in the walls of the MHD channel take advantage of this imbalance and provide the beginning and terminal points of a DC electric circuit. The plasma in the MHD channel acts as an electron donor.

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[6] Ibid., p. 4.1 - 4.16.

The strength of the magnetic field determines the amount of electrical energy which can be extracted from the conducting fluid. The MHD process requires a magnetic field strength of 50,000 to 70,000 gaus to operate efficiently and field strengths of this magnitude are now attainable.[7] New superconducting magnets require cryogenic cooling systems so that electrical resistance in metal components is minimized.[8]

The MHD channel is carefully designed to take optimum advantage of the magnetic field. The channel has a rectangular cross section. The side walls house the electrodes and the top and bottom walls are made of insulating material.

Electrode placement is a critical design factor because the electric field and the current direction are not collinear. To obtain maximum power, the channel must be divided into several electrically insulated segments. A suggested electrode material is tungsten with an iridium coating although successful long duration runs have been made with zirconium electrodes. Molybdneum compounds also

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[7] When development began an MHD high field strength was a technical barrier to MHD development; 30,000 gaus was the maximum field strength attainable. But by 1970 the Japanese had developed a 75,000 gaus magnet and American scientists had developed a 66,000 gaus magnet.

[8] As the temperature of a conductor approaches absolute zero (-273°C) molecular motion ceases and electrical resistance disappears. The Japanese magnet cools conducting elements down to -269°C.

have potential value as electrodes.[9] The electrodes may be separated by beryllia or strontium-zirconate blocks and backed with aluminum blocks, and the current collectors into which they feed could be made of molybdneum.[10]

Suggested materials for the channel insulating walls are zirconia or strontium-zirconia blocks.[11] Since zirconia loses its insulating characteristics and becomes a conductor at high temperatures, the zirconia blocks must be constantly cooled.

If the MHD system is the bottoming plant in a hybrid MHD-steam generator plant, the cooling water system for the MHD generator could function as a water preheat system in the steam generation stage.

The MHD channel must be constructed so that the inside walls can withstand thermal and abrasive effects of the plasma. Both the insulating walls and the conducting walls must be cooled. The superconducting magnet surrounding the channel requires a separate cryogenic cooling system. The MHD channel is the heart of the generating system. It

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[9] U.S., Department of Interior, OCR, Feasibility Study of Coal Burning MHD Generation, Vol. I, p. 21-23; F. A. Hals, W. D. Jackson, S. W. Petty, R. J. Rosa, and J. Teno, MHD Power Generation Status and Prospects for Open-Cycle System, (AVCO Everett Research Laboratory: Mass., November, 1969), p. 3.

[10] U.S., Department of Interior, OCR, Feasibility Study of Coal Burning MHD Generation, Vol. II, p. 192-193.

[11] Ibid.

is where thermal energy of combustion is converted into electrical energy.

Air Preparation--Air must be pressurized and preheated before entering the combustion chamber to maintain ionization temperatures. Air is compressed prior to preheating by conventional air compressors powered from the MHD generator. Once compressed, the air is forced through heat exchangers placed near the MHD channel exit. Air heat exchangers must be placed in the stream of hot gases leaving the channel. Gases leaving the channel cool down rapidly and solid particles develop in the plasma. Heat exchangers must be situated so they do not encounter matter in the liquid state. The corrosive effect of liquids is quite severe. A typical air preheater is shown in Figure 17.

Effluent Cleaning--Effluent gas contains seed, nitrogen oxides, sulfur oxides and fly ash.

The seed and ash are removed by electrostatic precipitation followed by a washing cycle. Flue gases exiting the air preheater pass through the electrostatic precipitator which collects a dry mixture of ash and seed. The cleansed gas next passes into the sulfur-nitrogen oxide recovery units. It is cooled compressed and forced through columns of water where nitrogen and sulfur oxides are absorbed as acids. The clean insoluble gases next pass through a turbine before being released to the atmosphere.

If necessary, the acids can be separated at additional cost. Markets for nitrate and sulfur products could make chemical recovery profitable.

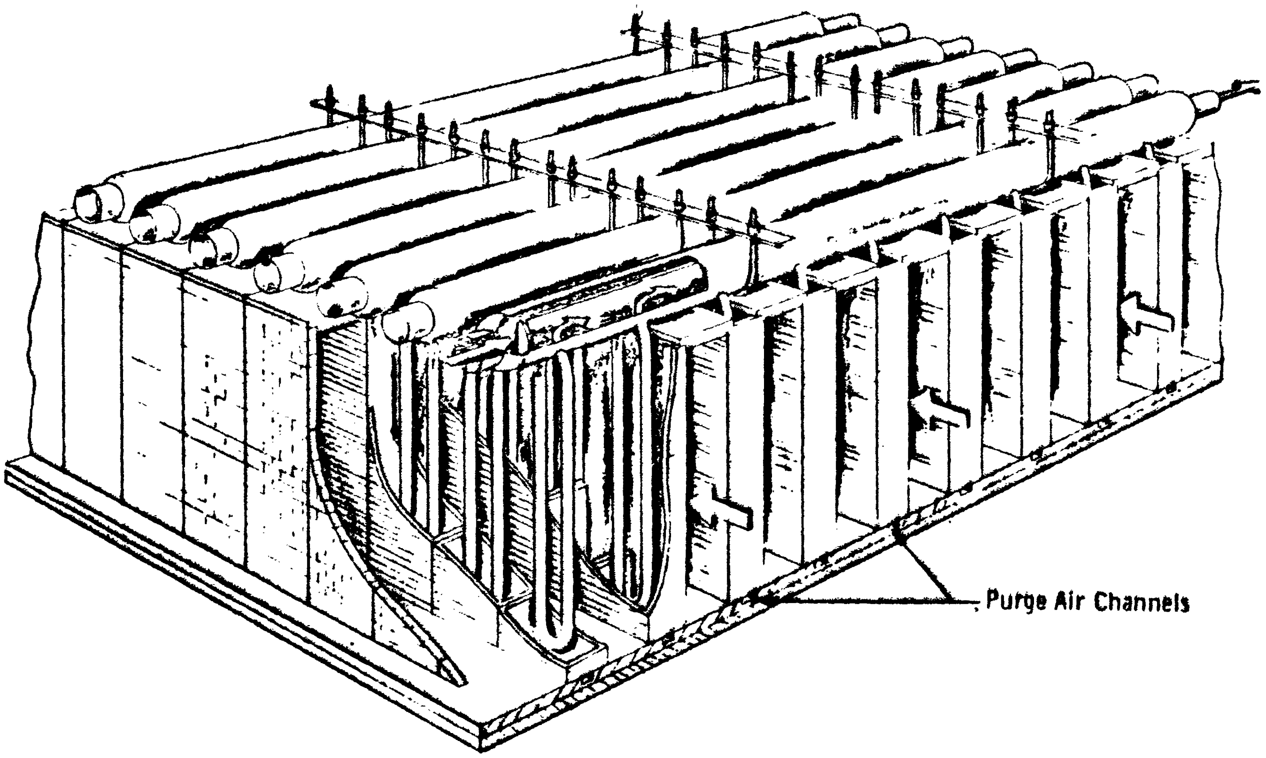

Fig. 17.--Proposed design for an MHD preheater.

APPENDIX III

Let W = amount of power produced in KWH

Fm = amount of fuel required to produce W KWH with MHD

Fc = amount of fuel required to produce W KWH with a conventional steam power plant

Nm = thermal efficiency of MHD $\frac{\text{BTU power per ton coal}}{\text{BTU thermal energy per ton coal}}$

Nc = thermal efficiency of conventional steam

k = conversion constant $\frac{\text{KWH}}{\text{Ton coal}}$

S = percentage fuel saved by using MHD instead of conventional steam generation

$$S = \frac{Fc - Fm}{Fc} \times 100$$

$$k\ Nm\ Fm = W$$

$$k\ Nc\ Fc = W$$

$$Nm\ Fm = Nc\ Fc$$

$$Fm = \frac{Nc}{Nm} Fc$$

$$S = \frac{Fc - Fm}{Fc} \times 100 = \frac{Fc - \frac{Nc}{Nm} Fc}{Fc} \times 100$$

$$S = \frac{Fc\ (1 - \frac{Nc}{Nm})}{Fc} \times 100$$

$$S = 100\ (1 - \frac{Nc}{Nm})$$

When Nc = 42%, Nm = 60%

$$S = 100\ (1 - \frac{.42}{.60})\ \%$$

$$S = 30\%$$

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