UNCONVENTIONAL ENERGY CONVERSION METHODS

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Introduction

The recent accomplishments in the field of direct energy conversion are receiving increased attention in the power industry since the potential rewards of lower costs are substantial. There would appear to be merit in a mutual consideration by the chemical and power industries of the possibilities and advantages of lower cost power in the chemical industry to be obtained through lower generation costs using new methods of energy conversion, and, of perhaps equal importance, through better and more effective utilization of the present facilities of large power systems.

Electric power companies have always engaged in system planning -- to predict future production and system requirements, and to apply new ideas and methods to reduce costs. Essential to any plan is the selection of generation methods producing the lowest overall cost, since this is the base to which all other costs are added. Consequently, it is important that we be actively engaged in and intelligently informed on these new system concepts so that they may be applied to our mutual advantage.

In considering the application of new methods of electric power generation, their effect in accelerating improvement of conventional methods should not be overlooked. Economic comparisons must recognize that present methods have been improved and costs reduced, and these methods will be further improved beyond what was anticipated earlier, because of the competition from new fields of technology, from improved efficiencies of conventional methods, or from other factors such as resulted from the unit-train delivery of coal to power plants.

Another example of a change which is beginning to have an important effect on power costs is the advent of commercially competitive nuclear plants. While nuclear power provides only a small part of today's generation, it promises to assume a significant part of the new capacity installed in the next ten or fifteen years. Nuclear reactors, even with present design, are now economic in some areas having high fuel cost, and in the near future will probably become competitive in all but the lowest cost fuel areas. Several of the advanced methods of power generation can be used to good advantage with a high-temperature nuclear reactor. Since such combinations can offer an important improvement in present nuclear cycle efficiency, their development may be accelerated along with nuclear power development.

In order that we may have some appreciation of the magnitude of the rewards we are talking about, a discussion of only one of the many items affected may be in order; namely, the fossil fuel bill of the investor-owned companies. The investor-owned companies in the United States at the present time spend about $1.6 billion a year on fuel. This will increase substantially in the years ahead because of increasing demands for energy. Figure 1 shows the Edison Electric Institute's estimate for power production by investor-owned companies for the next fifteen years.

Efficient as our present power plants are, there is still promise of developments ahead in conventional generating equipment and systems. Figure 2 shows the trend in net station efficiency for fossil-fuel fired plants, from 1940 to 1960,

and a projection to 1980. As indicated on this figure, developed in essence by W. D. Marsh of the General Electric Company, increases are likely to be achieved through the use of higher pressures and temperatures. There are other paths to increased efficiency, notably through the use of combined gas turbine-steam cycles, and possibly binary vapor cycles, using steam and mercury, or perhaps one of the alkali metals, potassium for instance.

Accordingly, the curve for the years 1970 to 1980 indicates a range of values to accommodate the possibility of achieving some of these cycles economically. It should be recognized that technically some of them can be built now, but either the economics or the operating complexities are such that they are not practical for average use at the present time. Figure 2 also illustrates the fact that the new methods of power generation promising higher efficiencies have a continually changing target to meet, one that becomes more difficult to achieve as the technology of conventional systems improves. For example, the probable improvement in the power field is indicated in Fig. 3. The table shows a substantial decrease in energy cost over a seven-year period and also indicates that nuclear power must be considered for any future capacity installations.

From the foregoing, it can be demonstrated that for an improvement in efficiency of 15 percent, for example, a fuel savings alone of about $200 million per year would be achieved by the year 1980, for only the new capacity installed. Such improvement is technically attainable, and within possible economic feasibility for several of the new methods of power generation. By providing lower cost power, it is hoped that these new methods will encourage developments of substantial new markets for the chemical industry.

The increasing demand for products from our two industries will require that larger sizes of equipment be installed. According to the Edison Electric Institute's forecast for the production of electrical energy for 1980, the power industry must either install three times as many generating units as it is today, or install the same number of units but three times the size of today's units, or some optimum combination thereof. It is probable that the installation of 1000 mw or 1500 mw generating units will not be an uncommon occurrence in the 1980s. The chemical industry can presumably expect to increase in a similar manner.

The increasing amount of "total energy" -- heat and electrical -- required to meet the increasing demands in the chemical industry will dictate some new and perhaps "unconventional" approaches when reviewing future production costs. The cost of this "total energy" would be considerable if produced by the chemical industry in smaller units, but could be at a relatively lesser incremental cost in the increased sizes which, it is predicted, will be installed by the power industry. Figure 4 is shown to illustrate the trend in reduction in capital costs and station net heat rate associated with the increase in size of generating units. These data are from Electrical World's 13th Steam Station Cost Survey, as published October 7, 1963. The chart is already outdated because station costs are even now 10 to 20 percent lower than shown in this chart for sizes of 500 mw and larger.

By taking advantage of the "total energy" supply concept, mutual advantages are possible. As a start in this direction, The Detroit Edison Company has purchased the power and steam generating facilities of two major chemical industries in its service area -- Wyandotte Chemicals Corporation and Pennsalt Chemicals Corporation. It is the philosophy of Detroit Edison that supplying of energy is its business and that it should be able to do so in a large system at a saving as compared to isolated smaller plants. The capital which the chemical industry would forego in investment for power and steam equipment could, it would seem, be put to more productive use in the expansion of product manufacturing facilities. Two of Detroit Edison's large chemical customers have agreed with this philosophy. I believe that there are mutual benefits to be gained by closer cooperation between our two industries. For instance, further benefits to both the chemical and power industries

may be possible if use can be made of the power industry's large off-peak generating capacity.

New Concepts

As indicated before, several of the new methods of power generation offer promise of commercial application to power system generation as a means of reducing production costs. The economic and technical status of the more promising of these are discussed in the following.

Thermoelectric

Of the four advanced concepts for power generation which are receiving most attention, the thermoelectric generator seems least likely to significantly affect the power industry. Thermoelectricity is beset with materials problems. The high interest in the late 1950s was generated by the development of semi-conductors and doped semi-conductors which produced a considerable increase in thermoelectric efficiencies. The initial enthusiasm has abated somewhat as no significant materials advance has appeared since then. However, small thermoelectric power generators have been built and operated. Home and office heating and cooling units involving thermoelectric devices are available at a price. Thermoelectric devices operating on hydrocarbon fuels have been developed for use primarily where low-wattage, continuous trouble-free operation is needed in remote areas. Thermoelectric generators fueled with radioisotopes are being used to power navigation buoys, remote unattended weather stations, as well as military and space applications.

Thermoelectric generation would still seem to finds its greatest application as a power consumer rather than as a power producer. For example, Fig. 5 was reproduced from a recent Sears, Roebuck and Co. brochure which offers "Coldspot Thermoelectric" buffet bars with a price range of $395 to $495. They also offer the working unit alone for $295 to use in some stationary spot in the home or office. Push buttons switch the unit from "keep-hot" to "keep-cool" or vice versa. Dials regulate the temperatures from below freezing to above 150 F. Others are offering this same or similar equipment.

Economic studies seem to indicate that thermoelectric generation will be limited in size and will be useful only in special applications. By 1980, capital costs may be reduced to the range of $200 to $500 per kilowatt of installed capacity. This could not be considered as economic for large scale power generation.

Thermionic

Thermionic generation is of significance to the power industry because of its adaptability to bulk power generation, particularly in central station reactor power plants. Reports from the large research and development effort indicate that the adaptation to space uses is on schedule, although the vehicles and missions which would require the 50-1000 kw nuclear-thermionic power supply may be further in the future than indicated heretofore. Figure 6 illustrates a space application of thermionic power.

An attractive commercial application of the thermionic converter is as an in-pile device for a nuclear reactor. Because the required emitter temperature is in the order of 3000 F, uranium carbide or a modification of it has desirable properties for such service. Consequently, it appears most practical to combine a thermionic topping device as part of a nuclear reactor. Since the efficiency of thermionic converters may ultimately reach 15-20 percent, a thermal cycle in which such devices are superimposed on a conventional cycle may significantly increase future plant efficiencies. However, other developments, such as nuclear superheat, may reduce the incentive for thermionic topping of reactors producing saturated steam. Perhaps equally important is the possibility of significantly increasing reactor capacities without commensurate increases in physical size or costs. However,

at present, it appears that economics will not favor commercial use of thermionic devices within the next ten years.

Magnetohydrodynamics

The commercial generation of power by magnetohydrodynamics, more conveniently referred to as MHD, appears to be associated with materials and costs. It is only fair to acknowledge that there is a difference of opinion in the industry as to the future of MHD in the United States. A combined MHD and steam cycle, in which gas from the MHD generators would be discharged to a steam-generator turbine-generator system, may prove in time to be economically feasible. As this would involve an open-cycle coal-fired MHD unit, problems are encountered with its molten coal ash, and high-temperature, strongly oxidizing gases in the duct, both in the MHD system and in the exit gas steam generator, and with the alkali seed material added for ionization purposes. Since the seed material is expensive, it would appear necessary that it be almost fully recovered. Such a cycle is described in Mr. J. J. William Brown's paper, "Some Aspects of MHD Power Plant Economics"[1].

The economic solution to these problems causes some pessimism as to the commercial attractiveness of open-cycle fossil-fueled MHD power plants in the near future. Consequently, closed-cycle systems, using so-called non-equilibrium ionization methods and those using liquid metal conductors, both of which permit somewhat lower temperature operation, are receiving increased attention.

One of the unusual aspects of MHD generation, offering mutual advantages to our two industries, is the possible recovery of nitrogen fertilizers and nitric acid. In the high-temperature gas flow conditions of the MHD generator, atmospheric nitrogen combines with oxygen to form nitric oxide. Fast quenching to low temperatures provides fixed nitrogen in the exhaust gas. Westinghouse Electric Corporation research engineers suggest that at current market prices this recovery process could prove to be economic.

The utility industry is supporting much experimental and developmental work in this country, and overseas as well. The Avco Corporation and a group of eleven electric power companies[2] have been engaged in a joint research effort on MHD for several years. The Edison Electric Institute is supporting a liquid metal MHD development effort with Atomics International.

Figure 7 shows an MHD binary cycle using liquid potassium for the MHD portion. The resultant low temperatures give rise to optimism for an economic breakthrough in the MHD field. Experiments are under way on several schemes utilizing either a two-phase liquid metal system, or two different liquid metals with dissimilar properties.

There is greatly increased MHD activity in Great Britain and France, most of it supported by the large nationalized utility industries. One of the largest overseas projects is that of The Central Electricity Generating Board of Great Britain which has a $5.4 million program for an open-cycle prototype MHD plant at its Marchwood test laboratories near Southampton, England. The prototype, designed as a topper to a conventional thermal station, is to have a thermal input of 200 mw and an electrical output of 20 mw. It will burn kerosene enriched with oxygen[3].

A major contribution towards the production of an MHD generator suitable for use as a topper in conventional power stations could be made by the new Electricité de France laboratory in Renardières, France. The MHD generator will have a continuous rating of 8 mw thermal at 3,000 K. The Renardieres' experiment will be on an open-cycle generator initially, but it is hoped to use an exhaust gas heat exchanger for preheating fuels at a later stage. This will be a fossil fuel-

fired device using a mixture of 20 percent potassium (by weight) and methanol for seeding the combustion gases in the MHD generator[4].

One of the main differences between this and other devices is that "wall phenomena" ceases to be of major significance when the MHD duct volume is increased. When the volume to surface ratio is low, heat losses through the walls, the effect of friction, boundary layers, and turbulence all have a significant effect on performance.

With high fossil fuel costs in many areas overseas, and the low carrying charges associated with nationalized power system economics, the incentive for MHD development is much different than it is in this country where we have (1) comparatively low cost fossil fuel, (2) competitive nuclear power in medium to high cost fuel areas, and (3) largely an investor-owned industry where carrying charges on investment are substantially higher.

Results of research and development look encouraging and there is still much enthusiasm in the MHD field. Pessimistic views exist, mostly in the predicted timing of an economic breakthrough.

Fuel Cells

The fuel cell field is highly diverse and one perhaps of greatest interest to the chemical industry. This diversity takes many forms, and makes economic evaluations complex and nebulous. For instance, one method of classifying fuel cell technology is by operating temperature, as follows: the low range temperatures, up to 150 C, use dilute aqueous caustic and acids; the intermediate range -- temperatures 150 C to 400 C -- use concentrated acids and pasty caustics; the high range -- 400 C to 800 C -- use molten carbonates; and the extra high temperature range -- over 800 C -- use solid ceramic oxides as the electrolyte. It is evident that within this wide temperature range, widely differing materials of construction are required, and there will be a difference in performance results, both resulting in variations in cost of manufacture, operation and maintenance.

Hydrogen-oxygen cells are probably the most advanced as a result of development in connection with the aerospace program. Indicative of this are the three fuel cells exhibited by Allis-Chalmers Manufacturing Company last November at the Arkansas Inventors Congress and Space Symposium -- (1) a 3 kw fuel cell system for NASA's Apollo spacecraft; (2) a 750 watt hydrazine-oxygen system used to power a small submarine; and (3) a lightweight 45-watt hydrogen-oxygen system. General Electric reports success with the hydrogen-oxygen type using an ion-exchange membrane, and Pratt & Whitney have been successful in developing a modified Bacon cell of the hydrogen-oxygen type -- to mention only a few of the many projects under way.

The regenerative fuel cell is of particular interest to electric power companies because of the possibility of using off-peak power for regeneration. Hydrogen-oxygen systems, hydrazine-bromine, and potassium-mercury cells are all under development, but considerable research effort will be needed before these systems can be considered to be commercially usable for power generation. In fact, this appears to apply to all fuel cell systems at the present time.

The very large research and development effort in the aerospace program, costing many millions of dollars annually, is responsible for the high degree of technical success of fuel cells. In a broad sense, it appears that we now have or shortly will have fuel cells available in 25 watts to 10 kw range of power, lasting up to three months at 70 percent thermal efficiency. They have the ability to function regardless of the attitude or orbit of the space vehicle. They are relatively immune to the rigors of space environment and can produce potable water as a by-product. Cost per kilowatt of capacity is very high.

Present economic studies indicate that at best the net energy costs for a hydrocarbon fuel cell will only approach those for conventional central station operation. The fuel cell may serve as a dispersed power source on electric systems, particularly for special applications such as peaking service where cost of operation is not the determining factor for economic use. They may also have application as a mobile power source, such as for use with fork-lift trucks.

Further development for varied and special commercial applications will depend to some extent upon private industry's continued willingness to invest in the necessary research and development. Regardless of the amount industry is willing to invest, we must continue close surveillance on developments in the major industrial fuel cell programs. There are about 21 such projects that, even if partly successful, could affect the future of the chemical and electric power industries.

I believe we should continue to invest in research and development to insure results favorable to our industries, and to make (1) more penetrating-engineering-economic studies to obtain the facts and calculations as to the real economic potential, and (2) a conscious search for fuel cells and applications that can be turned to the benefit of the chemical and electric power industries.

DC to AC Conversion

In most cases, the advanced concepts of power generation have one common characteristic -- they produce direct-current power. The present attractiveness of extra high-voltage direct current for transmission has encouraged the equipment manufacturers to the extent that the advances in DC-AC conversion techniques may be ahead of the progress in energy conversion. It would appear that, when the advanced methods are ready for application, DC-AC conversion will not be a major technical or economic handicap in the use of direct conversion devices. Where DC can be used directly, such as in the electrochemical business, the problem does not exist even now.

Cryogenics and Fusion

In considering advanced methods of energy conversion, note probably should be taken of the results of physical research in the two extremes of the heat spectrum.

1. Cryogenics, involving the investigation of matter at temperatures near absolute zero, has advanced to the stage where complete design guides are published concerning the entire range of engineering and chemical requirements, including properties of various substances, production systems, materials behavior, insulation, storage, necessary related equipment, and safety procedures. This is of particular interest in the development of MHD and fusion devices requiring high strength magnetic fields. Commercial cryogenic magnets are now available in small sizes. Larger sizes will presumably be available when the demand requires.

2. A large amount of government and private research effort is being devoted to the fusion reactor. Economic power from the fusion reactor still appears far away, almost certainly not before 1980, and probably later. It appears possible that energy released during the fusion of light nuclei to form heavier or more stable nuclei may be removed directly as electric energy, but up to now a continuous net production of power has not been achieved. When it is achieved, it will probably stimulate numerous

forecasts as to the impact of fusion on the world's sources of electric power. It is not practical at this time to give other than preliminary thought as to what cycles might be used with the fusion process, and the economic aspect of the process is still further removed in time.

Summary

In closing, I will use three figures of a previous paper[5/] which attempts to predict for the next twenty years generator size, power generation efficiency and capital costs for four methods of advanced power generation. On these figures, the information has been updated to reflect the changes discussed herein, as well as the effect of anticipated improvements in today's conventional methods, such as the recent trend of decreasing cost of coal at our power plants, and the increased efficiencies of nuclear plants.

Figure 8 shows the predicted generator sizes for the next 15 to 20 years. There is doubt of achieving the predicted sizes of thermoelectric generators for the years 1975 and 1980 because of the materials problem and what is considered to be a lesser probability of large scale commercial application. No one is now seriously considering the possibility of building a 200 mw thermoelectric generator, as was predicted several years ago.

The delay in achieving thermionic generator sizes reflects, in part, an anticipated lesser research and development effort, and also perhaps the effect of increased efficiency of present nuclear cycles which may make such devices uneconomic.

The delays indicated in the MHD field could be wrong. The present pessimism for an economic breakthrough in the cycle using fossil fuel could cause this sort of a delay. However, early success in the liquid-metals cycles or other low temperature gas cycles could suddenly spur the effort, but as toppers and not as large individual units.

In the fuel cell field, the 10 kw goal may soon be achieved as indicated before, mostly because of the huge aerospace effort. Whether the predicted sizes indicated for 1975 and 1980 are attained will depend, in part, on the degree of support for the necessary research and development by investor-owned industries.

Figure 9 shows the future predicted efficiencies for these four advanced methods of power generation. The same reasons which apply for the delay in developing generator sizes also apply for the delays indicated in Fig. 10, which shows the predicted capital cost per kilowatt net for these advanced methods.

These predictions are based upon the successful outcome of research efforts. When they will be achieved, is a function of the magnitude of the research effort which will, in turn, be affected by improvements in conventional cycles. Encouraging progress has been made, and our scientists, engineers and chemists will, I am sure, solve the many and complex problems of our future energy demands. It will be to the mutual benefit of both the chemical and power industries to work more closely together to develop more efficient methods of power generation, and more effective use of our present equipment.

References

1/ Some Aspects of MHD Power Plant Economics, J. J. William Brown, Manager, Direct-Conversion Projects, General Electric Company

2/ Membership of Group Supporting Work at Avco Corporation:

American Electric Power Company and Its Subsidiaries
Appalachian Power Company
Indiana and Michigan Electric Company
Ohio Power Company
Boston Edison Company
The Dayton Power and Light Company
Illinois Power Company
Indianapolis Power and Light Company
Kansas City Power and Light Company
Louisville Gas and Electric Company
Union Electric Company
United Illuminating Company

3/ Electrical World, September 14, 1964

4/ Electric Review, August 28, 1964

5/ Progress on Advanced Methods of Power Generation, H. A. Wagner, Assistant Vice President, The Detroit Edison Company; Presented at the 31st Annual Convention of EEI, Denver, Colorado, June 5, 1963

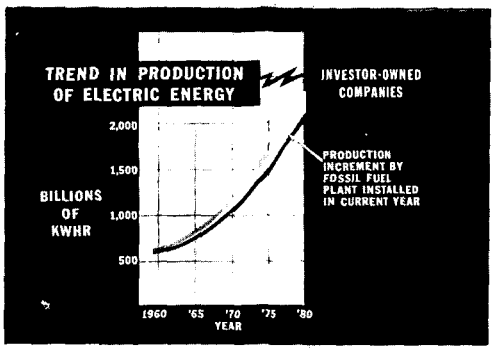

FIG. 1

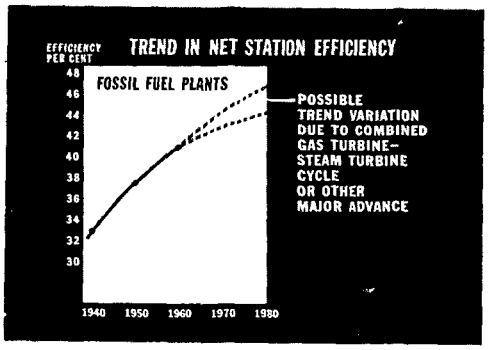

FIG. 2

COMPARISON OF PRESENT & PREDICTED ENERGY COSTS [a]

	PULVERIZED COAL		R.W.R.
IN-SERVICE DATE	1961	1968 *	1970 *
PLANT CAPACITY NET MW	327	515	550
CAPITAL COST $/KW	130	117	123
ENERGY COST MILLS / KWHR			
CAPITAL	2.09 [b]	1.83 [c]	2.02 [d]
FUEL	2.47 [e]	2.12 [f]	1.63 [g]
O & M	0.20	0.20	0.55 [h]
TOTAL	4.76	4.17	4.20

(a) AT 80% CAPACITY FACTOR
(b) 11.5 % FIXED CHARGES
(c) 11.75 F.C.
(d) 11.5 % F.C.
(e) 28.0 ¢/10⁶ BTU
(f) 24.0 ¢/10⁶ BTU
(g) LEVELIZED PRESENT WORTH VALUE OF 20 YR FUEL COST
(h) INCLUDES SAFETY INSURANCE
* ESTIMATE

FIG. 3

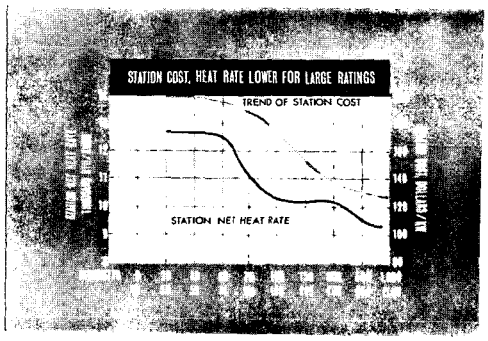

FIG. 4

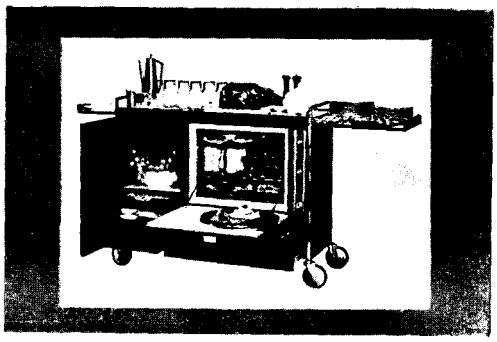

FIG. 5

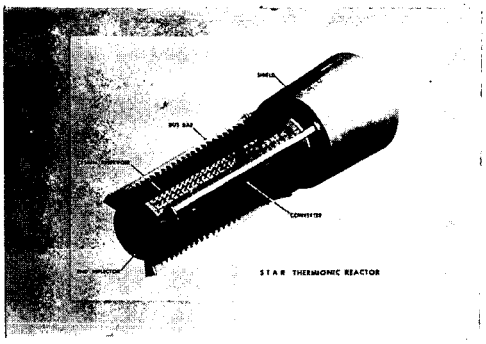

FIG. 6

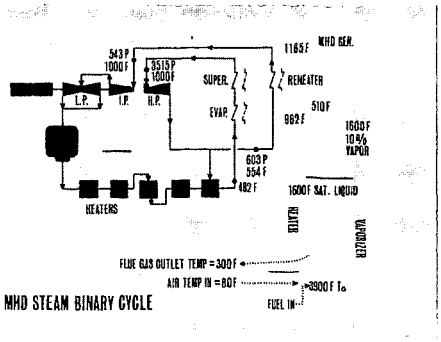

FIG. 7

FIG. 8

PREDICTED POWER GENERATION EFFICIENCY – %

YEAR	THERMO-ELECTRIC	THERMIONIC	MHD	FUEL CELL
1970	5	10	- - -	50
1975	10	25	50	60
1980	10	30-40	55-60	60+

FIG. 9

PREDICTED CAPITAL COSTS – $/KW NET*

YEAR	THERMO-ELECTRIC	THERMIONIC	MHD	FUEL CELL
1970	1,000-2,000	- - -	- - -	200-300
1975	500-1,000	1,000+	200-350	100-200
1980	200-500	200	150-250	50-100

* THESE DO NOT INCLUDE COSTS OF CONVERTING DC TO AC

FIG. 10