ly characterize the product antibodies. Edelman has evolved and refined theories to account for the presence of structural genes for particular antibodies at the time an organism is synthesizing them. He has advocated translocation of V_H and V_L genes to members of a group of corresponding C_H and C_L genes, respectively. Together with Joseph Gally (Meharry Medical College), he has also set forth possible mechanisms in support of the school which favors generation of some changes in immunoglobulin genes during somatic cell division.

Both Rod Porter and Gerry Edelman will be credited with inspiring the solution of remaining exciting problems in immunology, and in all likelihood will contribute to their solution. These problems include a correlation of primary structure with antigen-binding specificity, determination of the complete three-dimensional structure of IgG by x-ray crystallography, the synthesis of V_H and V_L regions with desired ligand-binding properties, a description of the genetic mechanisms leading to diverse antigen-binding specificities, and an understanding of the processes of lymphoid cell differentiation and cellular interactions that precede antibody synthesis.

JOHN J. CEBRA
Johns Hopkins University,
Baltimore, Maryland

Magnetohydrodynamic Power: More Efficient Use of Coal

ENERGY

Coal is the largest source of energy which is available now in the United States, but research into methods of improving the use of coal as a fuel has languished for lack of support. In recent years, however, more attention has been given to cleaning up coal-burning power plants, which despite their disadvantages are likely to continue as the mainstay of the utility industry for the rest of the century. Magnetohydrodynamic (MHD) generators that convert heat from combustion gases directly into electricity constitute one possible alternative, in that the high efficiency attainable with this technology would lead to reduced consumption of fossil fuels and markedly reduced thermal pollution. Perhaps surprisingly, it now appears that MHD generators also offer one of the best methods of eliminating sulfur oxide and reducing nitrogen oxide emissions from coal-fired power plants.

Despite its promise, MHD has yet to be demonstrated as a practical technology, in part because support for construction of large-scale experimental facilities has not been available. Substantial technical problems associated with the endurance of the equipment remain to be resolved—MHD generators operate at elevated temperatures, typically 2400°C in the gas entering the generator, and the hot residues from coal combustion are extremely corrosive—although most scientists in the field are confident that these will not present serious obstacles. Because the technology has not been demonstrated, its economic prospects are still uncertain, but preliminary estimates are favorable.

Research on MHD is becoming worldwide, with active efforts in Japan and several European countries. Several laboratories in this country are working on MHD with support from the U.S. Department of Interior and the utility industry. A more ambitious effort is being conducted in the U.S.S.R., which is already testing an experimental 75 megawatt power plant incorporating an MHD generator. Recent U.S. visitors report that the plant has so far produced up to 4 Mw for brief periods and seems to be operating successfully. The Russian program is primarily oriented toward the use of natural gas as the fuel—a choice that makes design of the generator not as difficult as for ash-laden fuels such as coal.

The MHD generator is basically an expansion engine in which hot, partially ionized gases flow down a duct lined with electrodes and surrounded by coils that produce a magnetic field across the duct. Unlike the gas in a turbine, the expanding gas propels only itself, and the movement of the electrically conducting gas through the magnetic field generates a current in the gas that is collected at the electrodes. Thus MHD generators are compact, have no moving parts, and can potentially accommodate temperatures and corrosive gases that would destroy conventional turbines. Very high temperatures would be necessary to ionize combustion gases; but with the addition of small amounts of potassium or other alkali metals, temperatures in the range 2000° to 2500°C provide sufficient ionization to allow the process to work.

Power plants incorporating MHD generators would include, in addition to the generator itself, pressurized combustion chambers for burning the fuel and heat exchangers or other equipment for preliminary heating of the air fed to the combustor. The preliminary heating appears to be necessary to reach the required temperatures, unless oxygen in large quantity is added to the fuel mixture, a procedure that would be uneconomical at present. Exhaust gases from the MHD generators themselves would be used, in full scale power plants, to generate additional electricity with conventional steam turbines; in most designs, MHD would provide about half of the electricity from the combined plant. The overall efficiency of the combined generating facility is expected to reach about 50 percent in the first full-scale MHD plant, as compared to 40 percent for the best conventional or nuclear power plants; and with more sophisticated MHD designs the efficiency could reach 60 percent.

MHD generators need stronger magnets than ordinary generators do because of the lower conductivity of gases as compared to copper, and superconducting magnets will probably be used in commercial plants. Large superconducting magnets have been built for applications in high energy physics, but relatively few have been built for MHD purposes and they are still very expensive. Research with the field strengths equivalent to those that will probably be used in MHD power plants (50,000 gauss) is only beginning. The electricity produced from MHD generators is inherently direct current, which must be converted before transmission over existing networks.

Endurance of the generator remains the most substantial problem facing those working on MHD. Only limited experience with long-term operation has been gained—a few-kilowatt generator at the Avco Corporation in Everett, Massachusetts, has been operated for several hundred hours and a 70-kw generator has been run for 500 hours in the U.S.S.R. The major question about long-term durability is whether leakage of current and arcing between electrodes due to condensation and penetration of the seed material into the generator wall can be avoided. Other potential problems include plasma instabilities in the ionized gas arising from interactions between the flow and the magnetic field; corrosion of the generator walls or of the air heater by coal ash may also present difficulties.

Several generator designs have been proposed, but not yet tested, to overcome these problems. In the Avco design, coal ash will be deliberately allowed to condense on the generator walls, building up a protective layer that R. T. Rosa of Avco believes will keep seed material from shorting the electrodes. Research groups at the University of Tennessee Space Institute in Tulahoma, Tennessee, at Stanford University in California, and at the Westinghouse research laboratories in Pittsburgh, Pennsylvania, have proposed still other designs. For example, the Westinghouse team, headed by Stuart Way, prefer a design with hotter wall temperatures that will prevent ash buildup; Way believes that cleaner fuels than coal—such as char, which is produced as a byproduct in coal gasification plants—may ultimately be preferable for MHD. But there appears to be general agreement that the problems can be solved, and that long-term testing and further experience with a pilot plant will be necessary to arrive at the best design.

Perhaps the most promising aspect of MHD power generation is the potential environmental advantages of these plants over traditional coal burning plants. Experimental work directed by Daniel Bienstock at the U.S. Bureau of Mines laboratory in Pittsburgh, Pennsylvania, has confirmed that the seed particles react with sulfur to form potassium sulfate or similar compounds which are relatively easy to precipitate (*1*). Because the alkali particles are recovered from the exhaust gases by cloth traps or electrostatic precipitators —indeed, must be recovered and recycled for economic reasons—essentially all the sulfur can be removed from even high-sulfur coals.

Nitrogen oxide emissions, which at one time were expected to be a problem because of the high temperatures in MHD plants, can also be reduced, Bienstock finds, if the coal is burned in a fuel-rich mixture and excess air is added further downstream. Work at Avco and in Japan has confirmed the Bureau of Mines results. Detailed calculations at Avco of the kinetics of the nitrogen oxide production and consumption indicate that the temperature and composition of the combustion gases can be controlled to reduce NO_x concentrations to acceptable levels.

If the predicted efficiencies can be achieved, and several independent analyses of the potential of MHD indicate that they can be (*2*), thermal pollution resulting from discharge of waste heat into cooling water would be reduced substantially, and would be less than that arising from any existing power plant. If gas turbines were used as the second half of an MHD power plant, the steam cycle and the need for cooling water could be eliminated.

Reliable estimates of the cost of MHD plants are not yet available, although there appears to be general agreement that construction costs should be approximately the same as those for traditional coal-fired plants and that, because of the more efficient use of fuel, operating costs per kilowatt would be significantly lower. The cost of the magnets is the largest single item, and the air preheaters are also expected to be expensive. Hence reductions in the cost of superconducting magnets or the cost of oxygen, which by enriching the fuel mixture would reduce the preliminary heating and hence the cost of the equipment, could further improve the prospects for this source of power. Developing the technology will be neither cheap nor without some financial risk, so that in the absence of substantial federal funding—which has not been forthcoming; current R&D spending is at the rate of about $3 million per year—only limited progress can be made. Both demonstration and commercial power plants will probably have to be large, because the power output of an MHD generator increases in proportion to its volume, while most of the losses increase in proportion to its surface area; 100 Mw is estimated to be the smallest size feasible for a plant that does not use oxygen enrichment.

The use of coal or fuels derived from coal to generate electricity carries with it the high cost to the environment and to human health that is associated with the mining of coal. But this energy source will not be replaced overnight; indeed the production of coal is expected to increase in coming years, so that efforts to improve the use of this fuel would seem well worthwhile. MHD generating plants would, at the very least, diminish the impact of mining by producing equivalent amounts of power with less fuel. What appears to be needed, as one proponent put it, is to "give MHD a chance."

—ALLEN L. HAMMOND

References

1. D. Bienstock, R. J. Denski, J. J. Demeter, "Environmental Aspects of MHD," in *Proceedings of the 1971 Inter-Society Energy Conversion Engineering Conference* (Society of Automotive Engineers, New York, 1971).
2. "Open Cycle Coal Burning MHD Power Generation: An Assessment and a Plan for Action," Report of the MHD Power Generation Study Group, Massachusetts Institute of Technology (U.S. Government Printing Office, Washington, D.C., 1971).

Speaking of Science

Frog Shortage Possible This Winter

The acute shortage of gravid (egg-bearing) female *Rana pipiens* that occurred last winter will probably be repeated this year, according to Frank Nace, director of the University of Michigan Amphibian Facility at Ann Arbor.

Large numbers of frogs died during hibernation last winter, primarily from septicemia. The total number of dead is unknown, but three major dealers in the western United States, for example, lost more than 90 percent of their stock. Normally, some 15 to 20 million frogs are used each year for research and educational purposes.

Although the cause of last winter's epidemic is not definitely known, Nace suggests that an unusually large spawning in the spring of 1971 and a drought that summer depleted the frogs' food supply. Most of the frogs thus went into hibernation in a state of semistarvation and were particularly susceptible to bacterial infection.

Preliminary indications from the fall migration collections now in progress suggest that a high mortality rate can be expected again this year. Although the shortage will probably be less severe, he adds, "investigators who need gravid animals should order their winter supplies immediately." At least one major dealer contests this view, however, arguing both that enough frogs will be available and that dealers are better able to maintain them during hibernation.—T.H.M.