Energy Needs versus Environmental Pollution: A Reconciliation?

A power generation concept by which pollution of air and water can be reduced is proposed.

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Processing and combustion of fuel is the principal source of air pollution in 1963 and, it is believed, will be the principal source in 1980 and 2000.
—Energy R & D and National Progress

The pressing problem of environmental pollution and its aggravation by increasing energy requirements has been elaborated by the comprehensive reports of two prestigious presidential study panels (*1*, *2*) and an eminent congressional advisory panel (*3*), by two recent national conferences in Washington, D.C. (*4*), and by repeated pronouncements in the press. The quotation given above is from the long-awaited Cambel report (*1*), which identifies the three most noxious atmospheric pollutants (carbon monoxide, nitrogen oxides, and sulfur dioxide), plus other toxic, carcinogenic, or corrosive compounds resulting from the combustion of fossil fuels in automotive or central-station power plants. The long-term consequences of the "greenhouse" effect due to CO_2 buildup in the atmosphere are also of serious concern. Furthermore, it is anticipated that the increasing use of nuclear power plants will play only a minor role in satisfying U.S. energy requirements through the rest of this century (*5*) and thus will do little to lessen the problem of atmospheric pollution and may actually aggravate the thermal pollution of rivers and estuaries because of the lower thermal efficiency of nuclear plants—at least of today's nuclear plants (*6*). It is generally hoped that ultimate salvation from air pollution lies in the eventual use of electric motor vehicles powered by fuel cells or by batteries recharged by nuclear central stations (*7*). In the meantime, the problem is already critical, and the question of thermal pollution has received relatively little attention.

Most of the recent specific proposals for relatively short-term improvement of this rapidly deteriorating situation—the proposals advanced by the three study reports and the recent AAAS conference papers—strike me as pecking at the edges of the problem. The congressional report fatalistically concludes that "if carbon dioxide emitted to the atmosphere from the combustion of carbonaceous fuel is found to increase the temperature of the earth, we have no way to stop it." Also, "The removal of sulfur dioxide from stack gas is still so costly that alternative measures such as very high stacks or special low-sulfur fuels are preferred." Indeed, stacks 1000 feet or more high (and costing $1 million or more) have been suggested (*8*). Instead of eliminating pollution, of course, such measures only distribute it more equitably.

On the other hand, recognizing that to remove the offending elements (carbon and sulfur) from the fuel prior to combustion is a much more efficient and less expensive procedure than trying to clean up the combustion products, the interdepartmental study identified the core of the problem (*5*): "An important energy issue lies in the extent to which the increasing atmospheric pollution from fossil fuel combustion may require imposition of further regulations on the use of these fuels." This statement may strike fear in the fossil fuel industry, but a resolution of the energy-versus-pollution conflict is possible. Outlined below is a concept for energy generation in which the fossil fuels are not burned directly but serve as raw materials for the synthesis of a "clean" fuel by a process which can be made more economical by nuclear energy in a fashion accessory to, rather than competitive with, chemical fuel production. This "clean" fuel is ammonia, whose complete combustion with air yields a valuable and beneficial product—pure water; its synthesis thus also constitutes a means for reclaiming used or otherwise polluted water.

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Large-Scale Production of Ammonia

The practical use of ammonia as an engine fuel is not new. Ammonia was used on a limited scale by Ammonia Casale, Ltd., in 1935 (*9*) and on a more extensive scale in Belgium in 1942, because of the petroleum shortage caused by World War II (*10*). More recently the use of ammonia has been investigated by the U.S. Army Materiel Command as part of its "energy depot" concept for increasing mobility (*11*, *12*). In that scheme, nuclear energy would be used to synthesize ammonia from air and water, but at high cost. Anticipating the future availability of large blocks of low-cost nuclear power, an AEC study (*13*) predicts production of ammonia from the electrolysis of water at prices competitive with those of today's commercial methods.

In commercial high-tonnage production of ammonia, however, natural gas is used as raw material for steam reforming to generate hydrogen for the synthesis reaction. In the course of this process sulfur is removed and recovered in elemental form, and CO_2 is scrubbed from the stream and may be recovered for sale or use. Although current practice is to discharge this CO_2 to the atmosphere, the point is that the CO_2 is under control and can be condensed or caused to react so that the carbon is tied up in some useful form. Because of the high percentage (by weight) of carbon in hydrocarbons, large amounts of CO_2 are recovered per unit of ammonia produced, and the commercial value of this CO_2 will have a major bearing on the economic attractiveness of the concept.

For a typical large modern plant,

the cost of manufacturing ammonia can be about 3/4 of 1 cent per pound (*14*); with a scale-up of production the cost would be even lower. Moreover, by far the greatest factor in this cost, aside from raw material, is the cost of natural gas to provide heat to drive the highly endothermic reforming process. The possibility thus exists that the cost can be reduced still further through the direct use of nuclear heat.

It is recognized that our national supply of natural gas and oil is strictly limited. A National Academy of Sciences report (*15*) states that "in the United States the culmination [peak] in the production of crude oil is expected to occur before 1970, and that of natural gas before 1980." We should thus prepare now to be ready to fall back upon our extensive coal and shale resources, not for burning but as the raw materials for gas production, again using nuclear energy for clean process heat (*16*). By using the nuclear heat directly to sustain endothermic chemical reactions rather than converting it to electric power by way of a closed thermodynamic cycle of inherently limited efficiency, heat contamination of water resources can be avoided.

Applications

There are obvious practical difficulties in the use of ammonia as fuel for private automobiles, difficulties not so much of engine operation as of distribution and handling of the noxious material. Although large-scale shipping of ammonia by truck and tank car is commonplace today, its public marketing in "filling stations" would be more difficult. Also, complete combustion may be hard to realize in a reciprocating piston engine operating over a wide range of speeds, making frequent starts and stops, and in generally poor tune. Crashes in tunnels or other confined spaces could pose toxicity problems (although fire hazard would be less than it is with gasoline). It is by no means obvious that the operation of today's conventional piston-engine automobiles with ammonia as a fuel can be made routine. On the other hand, we must remember that an equally pessimistic prediction was made for the original horseless carriage, and that practical turbine-powered automobiles are far closer to final development than electric-powered ones.

On the positive side of the argument, in the case of stationary power plants and large vehicles, such as buses, trucks, and trains, now fully capable of using turbine engines efficiently, the problems of operation with ammonia should be minimal. If a one-cylinder, spark-ignited reciprocating engine can achieve highly efficient (98-percent) combustion of ammonia and produce oxides of nitrogen in concentrations no greater than those typical of operation with gasoline (*11*), a well-designed steady-flow combustor free of oscillatory behavior should be able to achieve essentially complete reaction to water and nitrogen. Also, the effectiveness of regenerators used to improve the efficiency of automotive turbine engines could be increased considerably in operation with ammonia, since problems arising from the blocking of a fine pore structure by carbonaceous products would be avoided.

To get a feeling for the quantities involved, let us consider the example of a modest-sized, 100-megawatt (electrical) stationary power plant. With an efficiency of, say, 33 percent, such a plant would require the generation of 300 megawatts (thermal), or 17 million British thermal units per minute. The heat of combustion of ammonia is 8000 BTU per pound; thus, a mass flow rate of slightly over 2100 pounds of NH_3 per minute would be required to supply this rate of heat release. The combustion process would produce about 3400 pounds of water per minute, or about 24,000 gallons per hour. This hypothetical power plant has no stack but, rather, a condenser and cooling tower. Furthermore, the heat of condensation is dumped to the air, not to a river, lake, or estuary.

Since the flow rate required for operation with NH_3 is only slightly higher than the output of the 1000-ton-per-day plant, for which we have reliable production cost figures (*14*), the fuel cost for this 100-megawatt (electrical) plant can be estimated at just under 10 mills per kilowatt-hour, and this estimate does not take into account the CO_2 recovered in the ammonia synthesis or the water produced in the combustion process. Conceivably even the nitrogen could be recovered for recycling through the synthesis process or for other industrial use. As noted above, the economic value of the recoverable CO_2 is critical to establishment of the net power cost, since a plant of the size described would produce about 800 tons of carbon per day in one form or another if methane were used as the raw material (*17*). Aside from CO_2 for commercial uses, valuable derivatives might include urea, soda ash, or salicylic acid. The basic power plant could thus be the center of an industrial complex, although one more modest than that envisaged for the large nuclear plant (*7*).

Potentially, by far the most productive use of such large amounts of CO_2, however, would be to accelerate the growth of plant life. The trick here would be, not to disperse the CO_2 into the general atmosphere, but to control the micrometeorology of selected planted areas to render these local atmospheres rich in CO_2. By thus speeding the completion of a carbon cycle, a principal by-product of the proposed antipollution power system could be made to contribute to increased food production. Because of the high density of CO_2 relative to air, such control would seem within the realm of economic possibility. In place of containment by fully enclosed greenhouse-type structures, containment by vertical barriers of the low-cost plastic film already widely used in agriculture might be sufficient, at least during periods of relatively little wind. Judicious planting of trees (after the fashion of the eucalyptus rows in California citrus groves) to reduce convection near the ground might be helpful. I am digressing far from my field, however, and must leave this line of conjecture to others, but the possibility seems no more far-fetched than the idea of heating citrus orchards by smudge pots.

The potential of the process for reducing water pollution by means of regeneration and reuse of water also deserves emphasis. In arid areas such as the Middle East and the U.S. Southwest, this "bonus feature" of producing pure water from pipeline gas should have some economic appeal of its own: for every pound of water invested in the steam reforming of methane, 2 pounds are produced in the combustion of the ammonia synthesized therefrom. The potential of the process for reclaiming used or otherwise polluted water is obvious. Whereas people resist the idea of drinking water recovered from sewage (*18*), a process plant is less squeamish. In fact, even the carbonaceous sludge cake could be recycled as feed for water-gas production, a reuse loop thus being completed, as advocated by Spilhaus (*19*). If anything, the water recovered from ammonia combustion would be too pure for the public palate and might require appropriate flavoring (or, for some tastes, possibly carbonation with some of the excess CO_2 available; this conceivably might lead to a demand for other CO_2 derivatives, such as sodium bicarbonate and aspirin).

Conclusions and Recommendations

In this article I have presented, for discussion, a proposed system for energy generation by which the principal sources of environmental pollution by power plants could be eliminated. For stationary power plants the concept appears feasible technically and, according to my "horseback estimates," perhaps economically as well, depending upon the economic value of the by-products of sulfur, CO_2, water, and possibly nitrogen, and upon the price we are willing to pay for a clean environment. Thus, a more thorough engineering and economic analysis to explore these and other factors in greater depth seems warranted. In the case of turbine-driven vehicles, the technical and economic feasibility of widespread distribution and handling of the fuel constitutes a serious question, but one which deserves equally serious consideration before the possibility is discounted.

The reports of the cited study panels notwithstanding, the technology required for the proposed system exists today, with one exception. This exception (which is not essential for trial of the system but will be required for its complete fruition) is the development of a nuclear reactor for the prime purpose of delivering process heat for the steam reforming of natural gas and, ultimately, for gas production from coal in a continuous process, such as those discussed by Pieroni *et al.* (*16*). Today's intermittent processes of coking and gas production are both archaic and themselves large sources of atmospheric pollution, and a development program aimed at advancing the technology of the coal industry in this regard would seem long overdue. The report of the PSAC Environmental Pollution Panel recommended "demonstration of the feasibility and economy of new developments for abating or controlling pollution through their use at Federal installations" and suggested the coal-burning TVA power plants as a likely place for such demonstration. This suggestion is doubly appropriate since the TVA is in a region of subnormal "atmospheric ventilation" (*8*). By design these plants are adjacent to the AEC's Oak Ridge National Laboratory, and such a location would seem ideal for an experiment on the wedding of nuclear and fossil sources of energy.

In comments on a preliminary draft of this article, proponents of "conventional" nuclear power pointed out that such power is hard to beat on the basis of cost, and that dissipation of heat to the air by way of cooling towers can also be accomplished in conventional plants (*17*). These observations are individually correct but not compatible: the low power costs cited are for very large plants [of the order of 1000 megawatts (electrical) and larger], and the costs of cooling towers and associated equipment needed to dissipate such large amounts of heat [of the order of 2000 megawatts (thermal)] to air from a closed cycle would offset the power cost advantage of the large plant.

In regard to the proposed use of nuclear process heat, Weinberg (*20*) has expressed doubt that much advantage can be derived from this approach because the temperatures involved are too high for low-cost reactors, and heat transfer from surfaces could involve materials problems. In the case of gas production, this is indeed an anticipated problem—not a technologically insuperable one, but a problem of reducing the cost of the materials required (*16*). Indeed, Weinberg himself has mentioned this possible use of nuclear heat in a recent publication discussing the steam reforming of coal to liquid fuel (*21*). Also, an improved process for synthesizing methane from lignite has recently been reported (*22*). Since the earlier studies date back a decade, a new look at the problems and costs involved relative to the benefits to be derived (not the least of which could be new vigor for the coal industry) would seem to be in order.

In the case of steam reforming of natural gas, the temperature level (about 1500°F) is such that the technology is available today, and a process-heat-reactor design study could be initiated without awaiting further developments.

References and Notes

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