These definitions are more important than they seem. Though restrictive to make the subject manageable, they still include devices of great diversity. *Fuel* as used here excludes important substances often included, such as atomic "fuels" (e.g. uranium) and metals such as zinc or sodium (1).

The words *directly* and *usefully* imply that the device has an anode at which fuel is oxidized and a cathode at which oxygen is reduced; and that the conversion proceeds at voltages not greatly below the maximum possible, and at reasonably high current densities. *Low-voltage* and *direct-current* are important to the electrical engineer, who knows of course that electrical energy of this kind, although different from that ordinarily generated and transmitted, is of greatest importance to the electrochemical industry.

The reaction between conventional fuels and oxygen liberates only enough energy to give us about 1 volt per cell under ideal conditions. As Figure 1 shows, electrochemical reactions normally generate direct current. Schemes have been proposed to produce what has been loosely called alternating current from fuel cells, but the electrical engineer need not concern himself with such cells in the foreseeable future.

WHAT ARE THE IMPORTANT CONVENTIONAL FUELS?

In order of decreasing reactivity: hydrogen (in a class by itself); compromise fuels; and hydrocarbons.

Hydrogen belongs by itself because it is simple and highly reactive, the first characteristic probably being responsible for the second. When hydrogen reacts at an anode, it loses only one electron per atom and forms simple products. This probably explains why hydrogen can give us high current densities (amps/sq. ft. of geometric electrode surface) with minimum loss of voltage from the theoretical. Current density and rate of electrochemical reaction are proportional.

Hydrogen has had a dominant position from the first in the fuel-cell field (see Figure 2), and hydrogen fuel cells and fuel batteries will be emphasized in this article. Hydrogen has serious disadvantages, among which only high cost and difficulties in handling and storage need be mentioned here. Because of these disadvantages, we must look to other fuels for the future.

The hydrocarbons, especially the liquid hydrocarbons, are among the most important and desirable of all fuels. Unfortunately they are low in anodic reactivity, and their reactions are complex and can lead to many products. They are strong where hydrogen is weak, and weak where hydrogen is strong. The direct hydrocarbon fuel cell is a most difficult research assignment, but its successful accomplishment entails rewards that would outweigh the difficulties.

As their name implies, compromise fuels are of reasonable reactivity, cost, availability, energy content, and not too difficult to handle or store. Methyl alcohol and ammonia are prime examples. Hydrazine would be for specialized applications were its price to drop ten-fold or more. The compromise fuels are likely to be the earliest successors to hydrogen in direct fuel batteries; hydrazine qualifies now for special military applications in which fuel cost is unimportant, and the toxicity of hydrazine can be tolerated.

So far we have not mentioned the commonest fossil fuel, coal. At the beginning of the century, scientists and engineers began to wonder whether the dream "electricity direct from coal" could be realized, whereupon the fuel cell, which had been almost dormant since Grove, suddenly became popular. In 1900, the overall efficiency of steam plants was only about 10%. At this efficiency, they would have offered much less serious competition to a fuel-battery central-station than today, when this efficiency is 4 times as great. Figure 3 shows how far one man, Jacques, progressed in making electricity directly from a carbon much purer than coal. The caption of the figure explains why we need not consider coal seriously in direct fuel cells today.

CAN INERT FUELS, SUCH AS HYDROCARBONS, BE USED TODAY?

Yes, but *indirectly*, by changing them to substances, mainly hydrogen, more reactive at fuel-cell anodes. Examples of such changes are the reaction of carbonaceous fuels with steam, which is being widely investigated, and the decomposition ("cracking") of ammonia, which will be used to provide hydrogen for a fuel-battery-powered submarine in Sweden. Indirect systems thus combine a chemical plant with a fuel battery, and the combination brings problems not present with the fuel battery alone. Ideally, the chemical process should be carried out in the anode chamber to facilitate heat and mass transfer. Indirect systems will be of great interim value.

OXYGEN OR AIR?

For applications such as space missions in which the nitrogen of the air cannot be tolerated, oxygen must be used at the fuel-cell cathode. For terrestrial applications in which the cost of oxygen is prohibitive, or for which it cannot be carried because of weight or volume restrictions, ambient air must be used. But the use of air has important drawbacks that concern the engineer.

Most fuel-cell electrodes are highly porous so as to make their true surface many times the geometric; this is one road to high geometric current density, current density being proportional to true surface area. At high current densities, cathode pores can become filled with nitrogen; this creates a mass-distribution barrier for oxygen and injures cell performance. One remedy is to make the cathodes very thin (10 mils or so thick) and the pores large, but this introduces problems of its own. Especially in a fuel battery, where passages must be narrow to conserve space, forced convection of the air will usually be needed for acceptable current densities (say, 100 amps/sq. ft.). As nitrogen leaves a battery containing an aqueous electrolyte, this gas may carry with it enough water vapor to interfere with cell operation. Particularly at high current densities, the carbon dioxide (about 0.03%) present in the air may give trouble with alkaline electrolytes either by precipitating solids in the electrodes or by reacting with the bulk electrolyte; scrubbing the air to remove carbon dioxide or frequent changes of electrolyte may be necessary. Clearly, "free as air" needs qualifications as regards the fuel battery.

The problems of air operation are important also because various air batteries that are not fuel batteries (e.g., zinc/air batteries) might be attractive for applications (such as vehicular) in which high current densities are needed. One desirable by-product of fuel-cell research are air cathodes that can serve other power sources as well.

HOW DO FUEL BATTERIES DIFFER FROM STORAGE BATTERIES?

Storage batteries do not use conventional fuels. Storage batteries contain the chemical energy they convert; hence they must be recharged when this energy is depleted. Ideally, the fuel battery can be an invariant converter that delivers energy so long as fuel and oxqgen are supplied.

These two kinds of power sources are complementary more often than they are competitive. Storage batteries are favored for high power over short times (starting an automobile or short space missions); fuel batteries are favored when the load profile calls for moderate power over longer times (space missions longer than several days). The trade-offs that must be made are not usually simple, and they must be bade on the basis of the complete energy system for the load profile in question; in the case of the fuel battery, for example, one must consider energy source plus fuel plus oxygen plus peripheral equipment with proper debit or credit for the reaction products. To handle high peak loads, storage batteries may be used and kept charged by fuel batteries in continuous operation.

Metal/air batteries, such as the zinc/air battery mentioned above, are hybrid devices; as regards the anodes, they are storage batteries; as regards the cathode, they are fuel batteries. A hybrid device of a different kind is the fuel-storage-battery of Figure 4, in which the fuel (methyl alcohol) is stored in the electrolyte (potassium hydroxide) that changes to carbonate as the battery operates; the solution must be replaced when the fuel is exhausted, and the cost of potassium hydroxide, unfortunately not negligible, enhances the energy cost. The cathode operates on air.

WHY DO WE WANT FUEL BATTERIES?

Because they are *convenient* and promise eventually to be *low-cost* sources of electrical energy. Cost must be judged relative to convenience: because of the convenience it offers, a fuel battery may prove successful in an application (e.g., a space mission) though the cost of the energy it produces is prohibitive by central-station standards.

WHAT CONSTITUTES "CONVENIENCE"?

Such qualities as—

1. High power rating for unit volume.
2. High power rating for unit weight.
3. Quietness.
4. Cleanliness.
5. Operation on air.
6. Continuous unattended operation over long periods.
7. Production of useful water.

In assessing Qualities 1 and 2, the *complete system* (see Figure 5) must be considered. As regards Quality 4, the ultimate is a hydrogen/oxygen battery in dead-ended operation; in other cases, complete oxidation of the fuel is the most desirable way of achieving a harmless battery exhaust. Quality 6 involves reliability, maintenance, and life. Quality 7 is important particularly on space missions.

WHAT MAKES FOR LOW-COST ELECTRICAL ENERGY?

1. High efficiency.
2. Low-cost fuel and oxygen.
3. Low maintenance cost.
4. Long life.
5. Low capital investment.

Not all the factors determining cost have been listed. Research and development costs have been omitted because they are impossible of general assessment: terrestrial fuel batteries benefit from the knowledge gained in developing fuel batteries for space missions. Research and development costs are high absolutely, and development costs are very high relative to research costs. Adequate life tests are expensive.

WHAT ABOUT EFFICIENCY?

The immunity of the fuel cell to the Carnot-cycle restriction (see Figure 1) was for long its greatest attraction. In a modern central station, the Carnot-cycle efficiency could be near 65%, and the overall efficiency near 40%. The overall efficiency of smaller energy sources that the fuel cell hopes to displace is considerably less than 40%. Statements by reputable authorities often mention efficiencies greater than 65% for the fuel cell, and the popular press is sometimes even more optimistic.

There are efficiencies of various kinds. We shall proceed conservatively, and define an overall efficiency called the *comparative thermal efficiency* for the fuel battery and for the fuel-battery system. These efficiencies are comparable with the 40% mentioned above for central stations. The two definitions are analogous.

For the battery (or the system):

$$\mathrm{Eff}_{CT} = \frac{\text{Net useful work}}{\Delta H \text{ of fuel consumed}}$$

In the denominator, ΔH is the *higher* heat of combustion of the fuel actually consumed in making available the net useful work in the numerator; some of this fuel may be consumed by peripheral equipment. In both cases, the electrical energy required by the peripheral equipment (such as pumps) with its demand for parasitic power must be subtracted from the gross electrical work ($\int Eidt$) available at the fuel battery terminals; the system efficiency may consequently be considerably lower than the battery efficiency.

The efficiency of a single fuel cell will usually exceed considerably the two efficiencies given above. Detailed discussion would take us too far afield. We shall simply say that under most conditions this cell efficiency is determined principally by the *voltage efficiency* under operating conditions. This efficiency is E/E, where E is the actual cell voltage and E is the maximum value of E, which can be calculated from thermodynamic data and could be realized only under completely reversible conditions.

The most important single characteristic of a fuel cell is its current density-voltage curve (Figure 6), which is an index of cell performance and therefore corresponds to an upper limit for the performance of battery and of system. The current *density* (not current) is chosen as abscissa, not only because current density is proportional to the rate of electrochemical reaction, but also because it helps determine watts/sq. ft., a ratio that helps establish the size and weight of a power source given rating.

As concerns efficiency, the vital feature of current density-voltage curves is that cell voltage always decreases with increasing current density in the useful operating range. To realize maximum efficiencies, the cell would have to be operated at current densities too low for doing finite work: microamperes from a large power source are seldom useful.

Overall efficiencies are often thought of primarily in their relation to fuel cost. We hope the time will soon come when such thinking is justified for fuel batteries. In this early stage of their development, however, overall efficiencies are important primarily because they determine unit capital cost (dollars per kilowatt) and in special applications (space missions, portable power sources) because these efficiencies fix the weight and volume of reactants that must be carried for doing a given amount of work.

HOW RELIABLE ARE FUEL BATTERIES? WHAT IS THEIR LIFE?

There can be no firm answers to these crucial questions until there has been much more experience with fuel batteries. The answers will differ with the type of battery and with the duty cycle for a given type. "Reliability" and "life" are concepts difficult of exact or general definition. In space applications where the fuel batteries are isolated and cannot be attended, life may be taken as synonymous with mean-time-to-failure, failure of peripheral equipment included. In Project Gemini, it will be remembered, all the difficulties to the time of writing were chargeable to the peripheral equipment—none to the fuel cells themselves. In terrestrial applications, where opportunities exist for adjustment, repair, and replacement, a battery or a system will have a useful life far exceeding mean-time-to-failure under the drastic conditions mentioned above. Reliability and maintenance costs cannot yet be assessed.

The life of single cells under steady load in the laboratory is thousands of hours: *uniformity* is the key to long life. When cells are assembled to make batteries, uniformity is more difficult to achieve (see below), with the result that the life of a single cell may be shortened below what it would have been were it operated alone. Further, when cells are connected in series, and the life of an entire stack is that of the cell which is the weakest link, statistical considerations lead to a stack life reduced considerably below the average life of a single cell operated alone. For terrestrial applications, it should be possible to choose conditions so that the life of the battery limits the life of the system.

This analysis is not meant to be discouraging. If individual cells show long life, as they do, electrochemical engineers should be able to design and develop batteries and systems of adequate life.

WHAT OF UNIT CAPITAL COSTS?

Unit capital costs (dollars per kilowatt) cannot be translated to energy costs so long as life is unknown.

What unit capital cost is reasonable depends upon the premium that the convenience of the fuel battery can command. In space missions for which the weight of other power sources is prohibitive, that premium is high. The premium is at a minimum in the usual large central stations. For a given terrestrial application (e.g., power sources for communication equipment), the premium is likely to be much higher for fuel batteries in military (as opposed to commercial) use.

A simple calculation will show the importance of unit capital costs in commercial applications. Fuel batteries are often suggested for utilizing waste hydrogen. With d.c. electrical energy at 1¢ per kilowatt hour, and with hydrogen and air at no cost, a hydrogen/air battery at $300 per kilowatt installed, operating continuously and requiring no service, would produce just about enough electricity to recover the capital investment in three years. There are no fuel batteries now on sale at anywhere near $300 per kilowatt that would operate for three years under the conditions stated.

Tentative estimates of tolerable unit capital costs for fuel batteries intended for commercial use will be given. These are opinions not based upon detailed information. For small (10 to 100 watt) power sources, over $1000 per kilowatt; such power sources will serve best where they can benefit from transistorized circuitry. For central stations, $100 per kilowatt. For first use in electric vehicles, $200 per kilowatt; for passenger automobiles, the ultimate dream, very much less. Building a reliable battery of adequate life for, say, $50 per kilowatt will not be easy no matter what the fuel.

In this early stage in the development of fuel batteries, considerations of unit capital cost warrant the prediction that the terrestrial use of these devices will occur first in small sizes and in military applications.

AT WHAT TEMPERATURES DO FUEL CELLS OPERATE?

The properties of the electrolyte are perhaps the most important determinant of fuel-cell operating temperatures. Of these properties, we shall mention only the electrical conductivity. One function of the electrolyte is to complete the electrical circuit (see Figure 1) by the transport of ions, and it is desirable to keep the resulting I (2) R losses low by close spacing of the electrodes and by choosing a temperature at which there is adequate conductivity.

Typical examples (temperature ranges approximate):

- Ion exchange membranes now available, below 100° C (See Figure 9).
- Aqueous acid electrolytes, up to 200° C.
- Aqueous alkaline electrolytes, up to 300° C.
- Molten carbonate electrolytes, 500–600° C.
- Doped zirconia (solid) electrolytes, 900–1200° C.

WHERE IS THE BOUNDARY BETWEEN RESEARCH AND ENGINEERING?

It is convenient, though imprecise, to say that the fuel cell belongs to research, and that the steps from cell to battery and from battery to system are engineering assignments.

WHERE DOES RESEARCH STAND?

Though research is never finished, one can say that enough is known about hydrogen/oxygen- and hydrogen/air cells to make the designing and building of good batteries feasible.

Most research problems relating to energy conversion can be formulated as materials problems because the drive for high performance strains materials to their limits. We shall not concern ourselves with the usual types of materials problems, which arise in connection with sealing, corrosion, aging, decomposition, or evaporation.

Electrocatalysis is the main research problem with fuels other than hydrogen. For present purposes, we may (imprecisely) regard electrocatalysis as the process that raises IR-free performance curves like those in Figure 6—that is, the process by which electrode reactions at constant temperature, pressure, and electrolyte are accelerated to give a higher current density at a given cell voltage. A good electrocatalyst must be inert toward the electrolyte, have large specific surface, active morphology, be or resemble a transition metal (see the periodic table of the elements), and (if necessary) double as a catalyst for chemical reactions that accompany the electrochemical reactions. Platinum is the best single electrocatalyst for fuel-cell electrode reactions as a group, though it is not the best for every reaction. But platinum is costly, needed for other purposes, and limited in supply. Science has not yet given us an understanding of platinum's unique position in electrocatalysis, and we have therefore no firm theoretical guide lines for attacking the electrocatalysis problem.

The rates of chemical reactions increase with temperature. Though electrochemical reactions have complexities that enter into the temperature dependence of their rates, one is justified in assuming that higher temperatures bring higher rates, and that the electrocatalysis problems should be less serious at higher temperatures. This advantage will be at least partially offset by the increasing seriousness of the several types of materials problems (see above). To illustrate, an oxide-ion electrolyte resembling doped zirconia, but of greater conductivity, would permit reduced operating temperatures for cells with these solid electrolytes and make them more attractive.

WHAT OF ENGINEERING?

The importance of uniformity in a battery was mentioned above: only if conditions are uniform in a battery can the performance of the battery approach that realized for individual cells on a laboratory bench. The attainment of this uniformity is an engineering assignment because it depends upon the control of transport processes. A fuel battery consumes reactants and generates products and heat and electricity. The processes that transport mass, momentum, heat, and electricity must proceed at rates that maintain conditions uniform within the battery. Nonuniformity can result in many ways and have many undesirable consequences, one of the more serious of which will be illustrated in Figure 7.

In addition to ensuring uniformity in the battery, the engineers must also choose materials of construction, regulate the electrical output of the battery, and make the step from battery to system. These engineering assignments have turned out to be more formidable than many had anticipated, and the engineer today carries the principal burden in making hydrogen batteries successful.

WHAT ARE SOME ELECTRICAL PROBLEMS OF THE FUEL BATTERY?

The electrical problems of the fuel battery are inherent in the performance curve of the fuel cell (see Figure 6). Two favorable features stand out: (1) At open circuit, voltage is maintained without measurable consumption of fuel, there being no net electrochemical reaction at zero current density. (2) Voltage efficiency, and hence overall efficiency in the usual case, is higher the lower the current density. These features make the *direct* fuel battery desirable for equipment that must stand ready to perform during long idling periods, or that operates most of the time at low load. These advantages may be reduced in an *indirect* fuel-battery system owing to the energy required to keep converter or reformer ready for operation when load increases.

The low voltage of the single fuel cell leads to electrical problems, which are generally less serious with hydrogen as fuel because it gives higher cell voltages at the same current density than do most others; hydrogen might yield $E=0.7$ volt at current densities where hydrocarbons give $E=0.3$. The obvious way to obtain needed high voltages from fuel cells is to connect them electrically in series.

As was mentioned above, the greater the number of cells in series, the greater the chance one cell in the stack will fail, and this will most often be a failure of the *least* reliable cell. This could simply open-circuit the stack, or it could have more serious consequences. If the failure resulted from an interruption of the hydrogen or oxygen supply, the other cells in the stack could "drive" the one affected and cause unwanted reactions to occur at the electrodes. This is the serious lack of uniformity mentioned above. As Figure 7 shows, this type of failure could lead to the generation of oxygen in the hydrogen (anode) chamber and to the generation of hydrogen in the oxygen (cathode) chamber, clearly an undesirable state of affairs.

For cells connected in parallel, complete failure will usually not occur until the *most* reliable cell has failed although there will have been a decrease in current prior to complete failure. From the standpoint of reliability, it is desirable to minimize series—and maximize parallel connections.

There is a limit to how far one can go. Maximizing parallel connections implies the handling of large currents and the incurring of high I (2) R losses, and there is the added difficulty that most electrical equipment operates at voltages considerably above that of a single cell. Solid-state dc-dc converters are now available at ratings from 20 watts to a few kilowatts, but these are inefficient at low input voltages. They are nevertheless valuable because they make it possible to reduce the number of cells connected in series, the extent of maximum reduction being set by the conversion inefficiency considered tolerable, and by the probability of failure of a cell in the stack.

Dc-ac inversion for small loads can also be accomplished, but only with heavier and more costly equipment than dc-dc conversion requires. At present, we do not believe that inversion of fuel-battery power on a central-station scale need be considered; if such power can compete on this scale at all, it will have to compete for dc applications, notably in the electrochemical industry. The industry provides a large market: perhaps 5% of the 200,000,000 kw total American generating capacity serves this market, about half of which produces aluminum.

The performance curve in Figure 6 also permits conclusions about operation at various power levels. As Figure 8 makes clear, operation at maximum power density is possible only at reduced efficiency, and this reduction becomes prohibitive at current densities above that for maximum power density.

HOW ABOUT THE FUEL BATTERY AS A CHEMICAL PLANT?

In space, the water generated by H_2/O_2 batteries will be drunk or used in other ways. The fuel battery will then be not only a dc generating plant but a chemical factory as well. Is this appealing concept likely to prove widely useful on earth? We think not.

It is true that many important chemicals are produced by oxidation, and that such oxidation can often be done advantageously at an anode. Although we do not exclude the possibility that electricity may be a useful by-product in special cases such as the oxidation of sodium amalgam in the preparation of caustic, we do not think the combination of chemical factory and fuel cell will prove generally useful for these reasons (3):

(1) The amount of electrical energy produced annually by the power industry is so large that the by-product electricity we are considering will appear very small beside it. For example, a rough estimate shows that the electrical energy produced in the United States in one month (5.6×10^9 kilowatt hours) is equivalent to all the sulfuric acid (32 million tons) made here in two years. (SO_2 is assumed as starting material.) Sulfuric acid was chosen because it is a high tonnage chemical, not because it is adapted to manufacture in a fuel cell. It follows that any chemical made in amounts below 1 million tons annually could not produce by-product electricity in significant amounts.

(2) The value of such by-product electricity is low relative to that of the chemical produced. This is true even in the case of sulfuric acid: less than 1 cent for the kilowatt-hour equivalent to 12 pounds of acid worth about 12 cents. This twelve-fold ratio will be much greater with most other chemicals.

(3) An electrochemical device must usually meet different requirements for the optimum generation of electricity and for the optimum production of a chemical. Conditions for the latter process can be more closely controlled if a voltage is imposed on the cell—if electricity is consumed instead of generated. An improved yield or a chemical of better quality should usually justify this approach.

SHOULD FUEL BATTERIES BE CONSIDERED FOR ENERGY STORAGE?

In space, yes, if solar-energy converters are available. The scheme here is to convert an excess of solar energy into electrical energy during the orbital day, use this excess to electrolye a working substance (e.g., H_2O), and recombine the products of electrolysis (H_2 and O_2) in a fuel battery to produce electrical energy during the orbital night. Electrolyzer and fuel battery here constitute a *regenerative system;* the two may be the same device. Such energy storage sounds attractive, but there are problems with both the solar converter and the electrochemical system.

A recent article on pumped storage by Friedlander (4) shows that this method of storing energy on a large scale is so economical as to make competition by electrochemical regenerative systems (see above) appear hopeless. The efficiency of such systems, being the product of the efficiencies of fuel battery and electrolyzer, is much lower than that of fuel battery alone.

WHAT IS THE PRESENT OUTLOOK FOR FUEL BATTERIES?

Anyone called upon to answer this question is entitled to quote Mr. Justice Holmes (5): "Every year if not every day we have to wager our salvation upon some prophecy based upon imperfect knowledge."

This prediction (6) was made before 1960: "The current increase in fuel cell activity, if maintained, makes it likely that fuel cells will serve as power sources in special applications within the next 5 years. Successful, practical model cells are already with us. The future of central-station fuel cells cannot be predicted today." Figure 4 and Figure 9 show that the first sentence of this prediction was not rashly optimistic.

Next, the reader should examine a recent, authoritative, and more detailed prediction by Lord Rothschild (7) speaking for "Shell" Research Ltd., where important fuel-cell work is being done. This is a conservative prediction, reconcilable with that to be made below.

The prediction that follows is made within these boundary conditions: 1. It is based on the published material we know. 2. It includes applications, such as space and military, in which the fuel battery commands a premium for convenience. 3. It assumes that air, when available, will be used at the cathode. Air is considered unavailable in space and under water. The prediction will not be documented and only a few examples will be cited.

Space.—The fuel battery has established itself for space missions (General Electric; Figure 4). Future missions are scheduled to use fuel batteries by

Pratt and Whitney—batteries based on the distinguished work begun over thirty years ago by Mr. F. T. Bacon.

Portable (carriable by one or two men).—Successful application within three years seems certain with power sources for military communication equipment in a preferred position.

Transportable (carriable by vehicle with batteries for propulsion excluded).—Already installed by Brown Boveri (Figure 4). Successful military applications of other types at higher ratings seem likely.

Propulsion.—Successful applications will come first on military vehicles. Golf carts with *hydrazine* batteries have been demonstrated by Allis-Chalmers. Military fork-lift trucks should operate on fuel batteries within 10 years. The Swedish submarine effort was mentioned above.

The passenger automobile seemingly affords the fuel battery a great opportunity, but unit capital cost is such a formidable hurdle now that other problems are scarcely worth discussing. For the present, effort should be concentrated on automobiles that use storage batteries (8) perhaps new types not yet in use, which might be replaced or augmented by satisfactory fuel batteries. English opinion holds that the locomotive or the fuel-battery-powered railroad car is a more promising application than the passenger automobile. Hydrogen/oxygen batteries to operate all three could be built at a high price today; it will be remembered that Allis-Chalmers used such a battery to power a tractor in 1959.

The Home.—Steady progress (Broers, TNO, Holland; Institute for Gas Technology, Chicago) being made on methane/air batteries with molten-carbonate electrolytes leads one to expect experimental home installations exceeding 20% in comparative thermal efficiency within 5 years; such fuel batteries would be connected to banks of storage batteries as energy reserve for peak loads.

Central Stations.—The earlier prediction (6) stands with a few added remarks. The central station ranks with the passenger automobile in difficulty as an application for the fuel battery. It differs from the automobile in that unit capital cost is a less serious hurdle here than overall energy cost. The future of the fuel battery in the large-scale generation of electricity seems linked to the future of natural gas. The growth of atomic energy installations, and the effect this will have on the coal industry, both enter the picture because one must look perhaps a decade ahead for the earliest time that a central-station fuel-battery might begin to be used. But there is hope for the fuel battery in smaller central stations that serve a single community—stations in which the use of heat and of electrical energy will be efficiently combined, and distribution costs will be reduced.

The reader wishing to reconcile our prediction with that of Reference 7 will note that we have stressed fuel batteries of low ratings, and included space and military applications.

A logical position at present seems to be that fuel-cell research should continue so long as significant progress is made, and that the engineering development of H_2/O_2 and of H_2/air batteries for favorable applications should be emphasized. Fuel batteries will prove themselves indispensable in some applications and useful in many others.

I gladly thank Dr. E. J. Cairns for his help on this paper.

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3. H. A. Liebhafsky and E. J. Cairns, General Electric Report No. 60–RL–2382C, "The Fuel Cell and The Power Industry", March 1960.

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5. *Abrams* v. *U.S.*, 250 U.S. 616, 624 (1919), Holmes, J., dissenting.

6. H. A. Liebhafsky and D. L. Douglas, Ind. Eng. Chem., *52*, 293 (1960).

7. Lord Rothschild, Science Journal, *1*, 82 (1965).

8. See for example Maxwell Boyd, "Electric 60 mph 'mini' out soon", London Sunday Times, Feb. 27, 1966.

Figure 1. By their chemical natures, fuels tend to give up electrons, and oxygen tends to capture them. This tendency leads to a transfer of electrons from fuel to oxygen during combustion. In the fuel cell, the same process is made to proceed at two electrodes in more orderly fashion.

Electrons are given up by the fuel at the anode, flow through the external circuit where they can do work, and are captured by oxygen at the cathode. The circuit is completed by the flow of ions through the electrolyte, which is virtually impervious to electrons. Note that the electrical transport resulting in work is a directed process throughout. This explains why the fuel cell escapes the Carnot-cycle limitation, which applies when heat energy (random) is converted into work (directed).

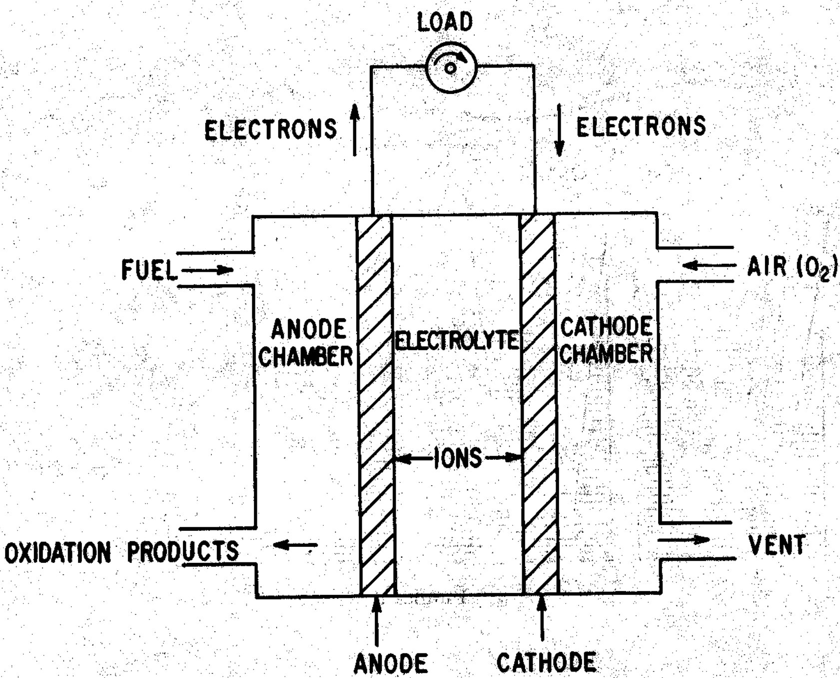

FIGURE 1

Figure 2. The First Fuel-Battery System (1842). Grove several years before had the dream of "effecting the decomopsition of water by means of its composition"—in our language, of using a hydrogen-oxygen fuel battery (four cells of which are shown connected in series above) as the power source for an electrolysis cell in which hydrogen and oxygen are produced. Twenty-six cells in series were required to decompose water in the upper cell. Sulfuric acid was the electrolyte, and the electrodes were platinum.

The combination of fuel battery and electrolyzer is the basis of regenerative electrochemical systems for energy storage.

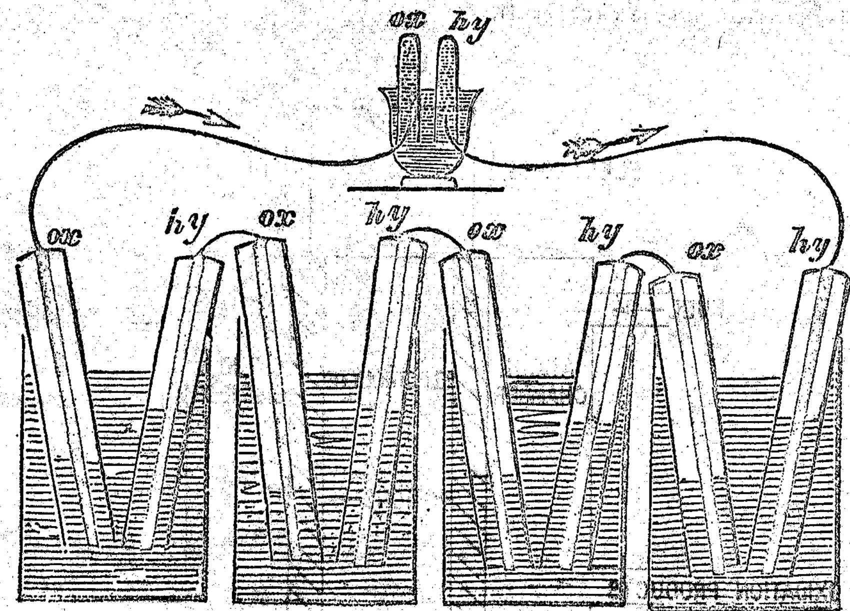

FIGURE 2

Figure 3. Another dream: "Electricity direct from coal" (Jacques, 1896). This carbon-air battery delivered 16 amperes at 90 volts and was said to have been in operation for 6 months when the picture was taken. The electrolyte was molten potassium hydroxide (costly) which was changed to potassium carbonate (cheap) as the battery operated. This alone makes the battery uneconomic. In addition, its efficiency—erroneously placed at "82 per cent of the theoretical"—was grossly overestimated, and the inventor did not come to grips with the difficulties that would have arisen from impurities (ash, sulfur) had he used coal.

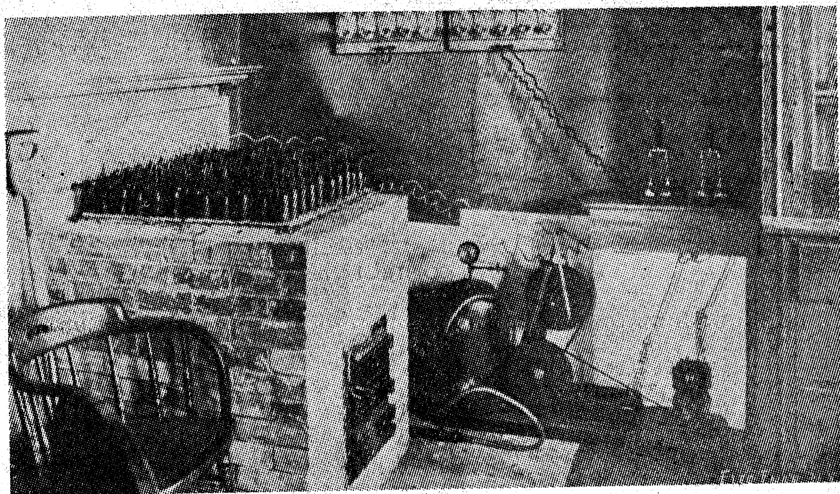

FIGURE 3

Figure 4. The fuel-battery system for Project Gemini. (Courtesy Direct Energy Conversion Operation, General Electric Co., Lynn, Mass.) Water transport to the accumulator is accomplished without moving parts by means of wicks and a pressure differential across a porous member.

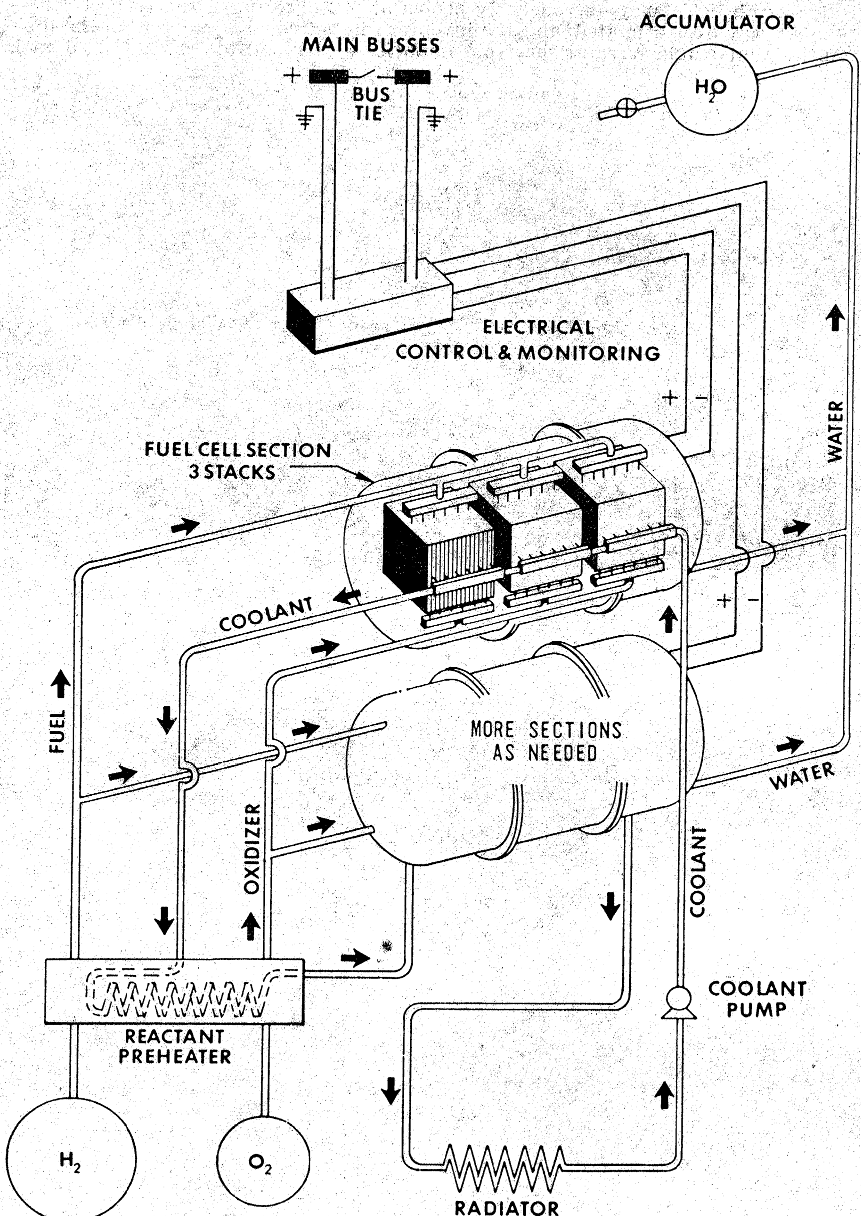

FIGURE 4

Figure 5. Idealized performance curve for a fuel cell. The value E=1.229 volts at 25°C is the maximum permitted by thermodynamics for a H_2/O_2 cell at standard conditions. In Region I, loss of voltage occurs principally at the electrodes. In Region II, this loss is increased by the internal resistence of the cell. In Region III, the perpendicular decrease in voltage results from a limitation in mass transport.

The equation for the curve is explained in Liebhafsky and Cairns "Fuel Cells and Fuel Batteries," soon to be published by John Wiley and Sons.

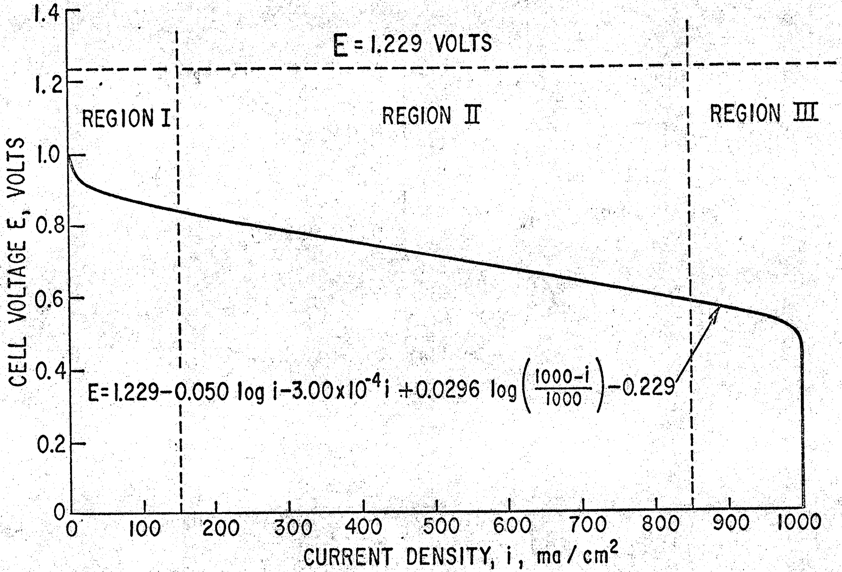

FIGURE 5

Figure 6. Consequence of One Kind of Lack of Uniformity in a Fuel Battery. Interrupting the supply of oxygen and of hydrogen to one cell in a series-connected battery causes the other cells to "drive" the afflicted cell. Undesired electrode reactions in the afflicted cell result.

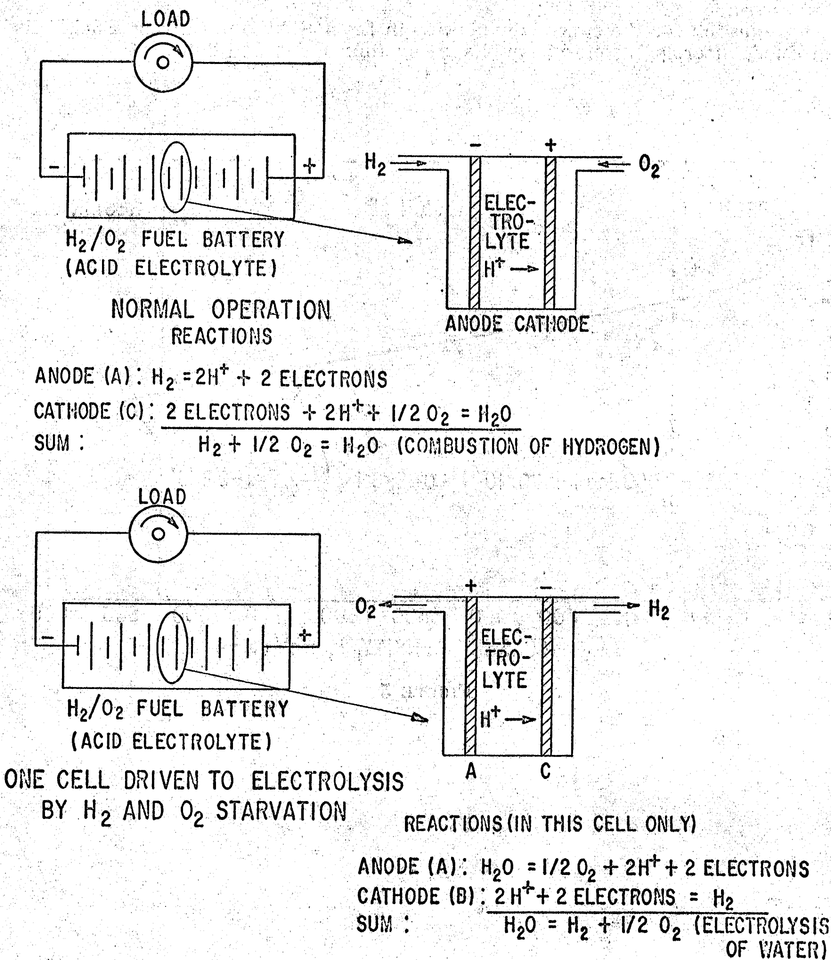

FIGURE 6

Figure 7. Idealized curve based on Figure 5 showing how the power generated by a fuel cell varies with curent density. Comparison with Figure 5 will show that the cell voltage at the current density for maximum power has fallen to about 0.6, which means reduced efficiency.

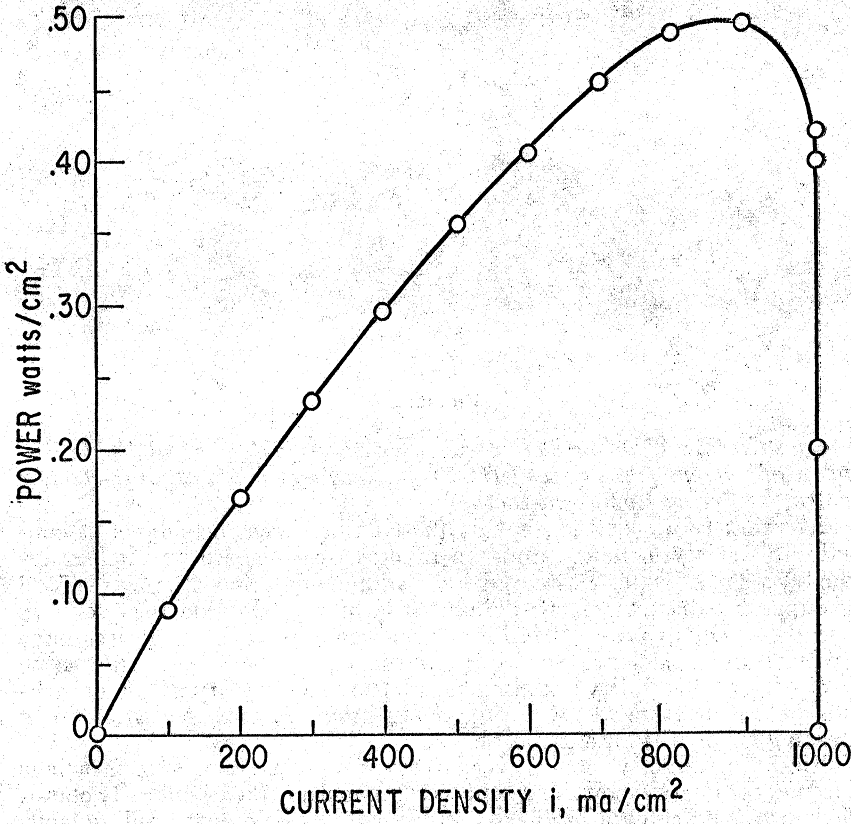

FIGURE 7

Figure 8. The Fuel Battery for Project Gemini. A pictorial history of its development by the General Electric Company.

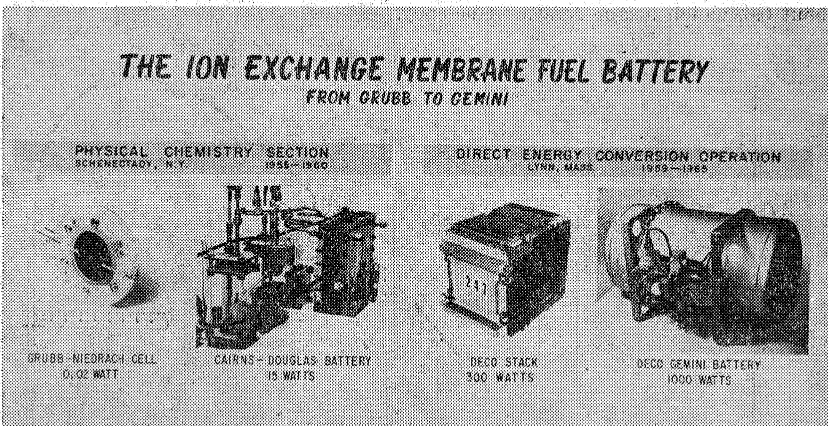

FIGURE 8

Question 2: What are your views on the problem of ultimate disposal of nuclear fuel wastes (after reprocessing) when nuclear-electric power becomes a dominant factor?

Answer: In a broad sense, this question has been the subject of considerable study, concern, and—in many cases—debate by nuclear industry professionals, State and Federal agencies, and other interested groups or individuals both domestically and worldwide for over two decades. During this time, high-level waste handling practices have evolved and sufficient operating experience has been accumulated to prove the applicability and, in general, the acceptability of these methods for radioactive waste storage on an interim basis, as contrasted to permanent or ultimate disposal.

Fission product wastes derived from solvent extraction separations plants (the current standard reprocessing method) are generally classified into four categories: high-, intermediate-, and low-level aqueous wastes, and gaseous wastes. The principal characteristics of these waste streams are as follows:

High-level wastes.—High-level waste is generally the waste raffinate from the first cycle of solvent extraction. This raffinate stream is acidic and contains 99.9-plus percent of all the fission products originally present in the spent nuclear fuel. The raffinate stream is normally concentrated by evaporation to yield a final waste solution of a few hundred gallons per ton of uranium processed. This final high-level waste solution is stored in either an acidic or alkaline form in underground tanks (either stainless steel or mild steel) with ancillary operating facilities and instrumentation to detect maloperation of the specific containment systems employed.

The water rejected from the waste concentration step above is contaminated with far lesser quantities of fission products than the original high-level wastes and is subsequently handled as an intermediate-level waste.

Intermediate-level wastes.—These wastes are generally composed of:

1. Second-cycle wastes derived from the solvent extraction process.
2. First cycle waste condensates.
3. Coating wastes derived from the chemical decladding of nuclear fuel elements.
4. Aqueous wastes accumulated from washing and purifying the organic extractant.

These wastes, either singly or pooled, are concentrated by evaporation. The distillate is routed to the low-level waste treatment system. The concentrated waste (still bottoms) is stored in underground tanks. The volume of intermediate-level waste generated per ton of uranium processed is several fold larger than that for the high-level waste.

Low-level wastes.—Low-level wastes are made up of water rejected from the distillation of intermediate-level wastes, process cooling water which has the potential of becoming contaminated, and other related process streams. This very large volume waste stream is treated by various methods to reduce the fission product content to acceptable levels and is then discharged to the environment. The fission products which were removed or "scavenged" from this solution are retained by tank storage on the plant site.

Gaseous wastes.—Gaseous wastes contain volatile fission products (for example, krypton and xenon) and other fission products that escape the chemical separations operations with process and ventilation air (for example, radio-iodine, tritium, and so forth). The gaseous wastes are treated chemically and filtered extensively to meet discharge limits for the disposal of gaseous wastes to the atmosphere.

CHARACTERISTICS OF WASTE STORAGE PRACTICE

From the foregoing, it is immediately evident that:

1. The fission product wastes are retained at the separation plant in a liquid and mobile form. Thus, these wastes are stored, not disposed of.
2. The only material disposed of, in the strictest sense and excluding the gaseous wastes, is water.
3. The integrity of the storage vessel is all important. Successive generations of storage tanks must be available as the original vessels fail from corrosion or other causes.
4. The storage system must be monitored continually to detect failure of the containment system resulting in the unwanted dispersal of fission products in a mobile form to the environs.

ACTIVITIES IN THE WASTE MANAGEMENT FIELD

The U.S. Atomic Energy Commission is currently supporting a multimillion-dollar program within the AEC complex to develop and demonstrate practical and economic means of converting high-level aqueous wastes, typical of those assumed to be produced by the commercial fuel reprocessing industry, to immobile solids. These fission product-containing solids, either as calcines or after conversion to "glasses," are to be packaged in high integrity metal containers suitable for permanent storage in special geological formations, that is, salt mines, and so forth. It is to be noted that the conversion of the liquid waste to a solid form results in an additional benefit; namely, the volume of calcined waste is the order of 1 cubic foot per ton of uranium processed as contrasted to a value of several hundred gallons per ton for the liquid waste. This program is scheduled for completion in the next 2 to 3 years.

Similar, but less extensive, programs are also being carried forward by the AEC for the conversion of intermediate-level wastes to immobile forms. Activities in the foreign field are also being pursued along technical lines paralleling those of the U.S. Atomic Energy Commission.

FUEL RECOVERY OPERATION—WASTE MANAGEMENT OBJECTIVES

During the 1970's and beyond, it is expected that nuclear electric power will play a major role in the domestic electric power field, and as a consequence there will be a considerable amount of activity in the commercial nuclear fuel reprocessing business with the attendant production of fission product wastes.

The General Electric Co., through its fuel recovery operation, plans to participate in this expanding commercial business and will employ a technically advanced (relative to solvent extraction) reprocessing system for the recovery of the valuable constituents of spent nuclear fuels.

The waste handling operations planned for this advanced process—the aquafluor process—are consistent with our overall views on radioactive materials waste management; namely:

1. The high-level reprocessing waste will be converted to dry, solid form and subsequently sealed in metal containers. These waste containers will be retained at the separations plant to permit periodic evaluation of the integrity of the packaged waste and to allow for waste accountability and/or retrieval, if desired.
2. Intermediate- and low-level wastes will be stored in a solid, nonmigratory matrix.
3. No liquid waste will be discharged to the surrounding surface or ground waters.

SUMMARY

In summary, it is our view that:

1. All high-level radioactive wastes should be converted to a solid, nonmigratory form.

   Since some of the fission products in high-level waste, for example, Sr–90, Cs–137, Pu–239, represent a significant hazard to man for many centuries, this waste should be packaged and stored so that surveillance and retrieval is possible.

2. Intermediate-level waste, although not as significant a hazard to man as high-level waste, should at least be stored in a nonmigratory matrix.
3. Gaseous wastes may be discharged to the environment as long as the radioactive content is below discharge limits as set by regulatory agencies. It can be noted, however, that recovery of krypton and xenon from gaseous wastes may become attractive as the separations industry matures. It is unlikely that their recovery would be based on health and safety criteria, but rather for their subsequent use as commercial chemicals.

Responses to Questions of the Subcommittee on Science, Research, and Development by Dr. Charles A. Bishop, U.S. Steel Corp.

Question 1: How does the steel industry view the possibilities for recycle of metals in manufactured goods—autos, refrigerators, and so forth?

Answer: The steel industry has through the years been a purchaser of scrap for recycle. According to a recent statement before the Senate subcommittee considering bill S. 3400, Mr. W. S. Story, executive vice president of the Institute of Scrap Iron & Steel, stated that in the past 2 years steel mills and foundries bought more than 30 million tons of prepared scrap annually. This included more than 6 million tons of auto scrap.

Scrap may be contaminated with foreign materials such as copper, nickel, zinc, lead, tin, aluminum, rubber, plastics, and so forth. While none of these foreign materials are helpful, at least three—copper, nickel, and tin—cannot be removed in the normal course of making steel. Accordingly, preparation of scrap by the scrap dealer is the only safeguard. However, I understand a great deal of thought is being given in many different quarters to solving the segregation problem by mechanical and magnetic methods.

In reading about the recycling of scrap, it is apparent that there are many ancillary problems, such as the collection of scrap in a neighborhood, the legal redtape as to the ownership of discarded vehicles, refrigerators, and other junk left on public property, and the ultimate transporation of the processed scrap to the steel plants.

Question 2: Regarding the need in a number of industries for a process to remove SO_2 from stack gases, could this best be attacked by Federal R. & D. contracts, or by an interindustry cooperative program, or by individual process engineering companies?

Answer: Since so many industries burn coal and oil, there is a broad interest in processes for removing SO_2 from stack gases. I believe that the initial studies should be carried out by Federal R. & D. contracts, either by Government agencies such as the Bureau of Mines, or by private research groups. For processes which show promise, grants should be made for demonstration plants to test the engineering design features.

RESPONSES TO QUESTIONS OF THE SUBCOMMITTEE ON SCIENCE, RESEARCH, AND DEVELOPMENT BY DR. COLIN M. MACLEOD, EXECUTIVE OFFICE OF THE PRESIDENT

Question 1: Could you describe existing coordination mechanisms within the executive branch for scientific activity in environmental pollution?

Answer: The President's Office of Science and Technology functions to coordinate scientific activities on environmental pollution in a variety of ways. In addition to providing advice and assistance to the President by evaluating programs and assisting to develop policies, the Office assists in coordinating agency activities through frequent formal and informal contacts with agency representatives.

The Office of Science and Technology maintains close liaison with the Federal Committee on Pest Control, including attendance at all meetings of FCPC. The Office also works closely with the Bureau of the Budget in providing leadership in the planning of Federal Government programs, organization, and policy on matters of environmental pollution.

The OST staff is presently analyzing and evaluating the responses of Government agencies to the President's request for recommendations as to how the Federal Government can best direct its efforts toward advancing understanding of natural plant and animal communities and their interactions with man, which is concerned directly with environmental pollution and natural beauty.

The Office provides a staff member to participate in the President's Council on Recreation and Natural Beauty.

The Committee on Water Resources Research of the Federal Council for Science and Technology has evaluated the needs for research in problems of water pollution by the Federal Government. Its recommendations on water quality management and protection are included in the report "A 10-Year Program of Federal Water Resources Research" (1966). The work of the FCST Committee on Water Resources Research was supported by the Panel on Water Resources of the Office of Science and Technology. The recommendations of the Panel are reflected in the report of the FCST Committee on Water Resources Research.

In addition to the 10-year program for water resources research, the Federal Council for Science and Technology has issued progress reports on Federal water resources research for each of the past 3 years.

The President's Science Advisory Committee, for which OST provides staff support, has studied in depth a number of major pollution problems and has made recommendations for policies and programs needed to alleviate them. Examples include the PSAC reports: "Use of Pesticides" (1963), "Restoring the Quality of our Environment" (1965), and "Effective Use of the Sea" (1966). At the present time the Office of Science and Technology and the Bureau of the Budget are analyzing and coordinating the responses of Government agencies to the recommendations in the report "Restoring the Quality of Our Environment" and will take actions based on this analysis.

Question 2: Is there a formal procedure whereby Federal activities which might result in lowering the quality of the environment can be reviewed in the light of broader public interest considerations? (Such a function might be similar to the Federal Committee on Pest Control.)

Answer: At the present time there is no organization whose primary responsibility is to review comprehensively Federal activities that might result in lowering the quality of our environment. The Federal Committee on Pest Control is concerned with insecticides, fungicides, nematocides, herbicides, and bactericides. In addition, the Special Assistant for Science and Technology, under a national security action memorandum, has the responsibility to review large-scale experiments that might have a deleterious effect on the environment. Major problems of environmental pollution have been evaluated from time to time by the President's Science Advisory Committee as noted above.

The evaluation the Office of Science and Technology and the Bureau of the Budget is presently making of the recommendations of the PSAC report "Restoring the Quality of Our Environment" and the responses of Government agencies to that report, includes consideration of establishing either an interagency committee on environmental pollution or a committee of the Federal Council for Science and Technology to be concerned with problems of environmental pollution.

The PSAC report made the following recommendations concerning identification of problems and coordination of actions:

"(a) The Federal Council for Science and Technology should establish a Committee on Pollution Problems, composed of its own members.

"(b) The National Academy of Sciences-National Research Council should be asked to establish an Environmental Pollution Board, to be supported by Government grant.

"(c) This NAS–NRC Board should meet jointly with the FCST Committee at least once a year to discuss newly recognized broad problems and current changes in the apparent importance of those previously recognized.

"(d) The Board and Committee should cooperate, through working-level mechanisms such as joint panels, to identify the most pressing broad problems, and the general character of new knowledge or techniques needed to study or ameliorate them."

Our current evalaution of the PSAC report is deeply concerned with these recommendations.

Question 3: What is your view on the "National Commission for Environmental Protection" suggested by the NAS report "Waste Management and Control"?

Answer: In my opinion a high-level planning and coordinating body should be established such as the "National Commission for Environmental Protection" suggested in the NAS report, or mechanisms such as were recommended in the PSAC report and noted immediately above.

When the OST/BOB evaluation of the PSAC Report "Restoring the Quality of our Environment" has been completed, we will be in a much better position to recommend what type of planning and coordinating body or bodies should be established.

RESPONSES TO QUESTIONS OF THE SUBCOMMITTEE ON SCIENCE, RESEARCH, AND DEVELOPMENT BY DR. JOHN L. BUCKLEY, DEPARTMENT OF THE INTERIOR

Question 1: Could you furnish a table or chart showing all of the Department of the Interior scientific activity in environmental pollution by subject and organizational structure; and any formal or informal coordination mechanisms with other agencies?

Answer: Department of the Interior Scientific Activity in Environmental Pollution:

Organizational Unit and Subject

Bureau of Mines:
- Air pollution: Removal of pollutants from fuels; improved combustion; removal of pollutants from stack gases.
- Solid wastes: Mining and manufacturing wastes; recycling of metals.
- Water pollution: Acid mine drainage control.

Sport Fisheries and Wildlife: Effects of pollution: Especially pesticides; acid mine drainage.

Bureau of Commercial Fisheries: Effects of pollution: Especially pesticides and radionuclides, pollution of estuaries.

Bureau of Reclamation: Water pollution: Especially irrigation induced salinity.

Federal Water Pollution, Control Administration: Water pollution: All phases.

Office of Coal Research: Use of coal in sewage treatment.

Office of Water Resources Research: Grant support of water pollution research, all phases.

Office of Saline Water: Waste treatment.

Geological Survey: Water pollution: Identification of pollutants, instrumentation, hydrology, water quality data. Waste disposal by deep injection.

Coordination with other agencies:
- Membership on Federal Committee on Pest Control and its subcommittees for pesticide matters.
- Formal liaison contacts for air pollution.
- Numerous informal contacts.

Question 2: What are your views on a policy which would reserve fossil fuels, particularly petroleum, for use as chemical raw materials, while accelerating the use of electricity generated by means other than fossil fuel combustion?

Answer: I personally believe that such a policy is necessary in the very long run. Known reserves of coal are adequate for the foreseeable future, and it will doubtless be possible to convert coal into gas or liquid fuels. Nevertheless, the twin advantages of reduced CO_2 generation and availability of the fossil fuels as chemical raw materials while they are still abundant enough to be cheap, strongly suggest the desirability of a policy that encourages gradual transition to other energy sources.

RESPONSES TO QUESTIONS OF THE SUBCOMMITTEE ON SCIENCE, RESEARCH, AND DEVELOPMENT BY MR. JOHN O. LOGAN, MANUFACTURING CHEMISTS' ASSOCIATION

Question 1: It is recognized that although pollution is caused by many different industries, it is a chemical problem. Therefore, regardless of source, how can industrial chemical technology best be brought to work on the solution?

Answer: The statement that "although pollution is caused by many different industries, it is a chemical problem" is an oversimplification. Actually, while all pollutants are chemical in character and amenable to chemical technology, it does not necessarily follow that the application of chemical technology is the most economic and practical answer to each pollution problem.

We believe the chemical technology of the industry can best be utilized along the following lines:

(*a*) The chemical industry voluntarily, as well as under incentive or pressure motivation, will devote additional attention to solving its own pollution problems. The solution to these problems in turn can be applied to other industries having similar problems. Motivation by incentive is probably the key to more rapid progress in this area.

(*b*) Chemically oriented companies who are in the business of water and/or air treatment can engage in pollution abatement effort for sale at a profit to any industry. This is currently going on and will be amplified and speeded up as the demand for this service develops.

(*c*) Establishment of chemical technology information exchange mechanisms via seminars and conferences along cross-industry lines. This involves the collection and dissemination of data so that maximum utility can be made of present information and new information as it is developed. The Manufacturing Chemists' Association, Inc., has for some years been fostering such information exchange. Currently the association has a program of 1-day workshops to assist in solving industrial pollution control problems in localized areas, with regulatory officials participating. In addition, week-long seminars have been arranged by MCA at five United States and one Canadian universities to provide instruction on the latest techniques for treating and controlling chemical wastes.

(*d*) By drawing on the counsel of chemically oriented people in devising control plans, developing control criteria, specifying research programs, and other areas related to pollution control, available chemical industry technology can be fully utilized. Members of MCA's Water Resources Committee are consulting with State agency officials with the objective of being helpful regarding the current development of water quality criteria under the Federal statute.

The history of the chemical industry demonstrates that it is alert to opportunities to engage in research along the lines of expanding technology, including that applicable to waste treatment and control. Hence as new ideas emerge, we do not believe there will be any lack of appropriate development by the chemical industry.

Question 2: What are your views on a policy that would conserve fossil fuels for chemical raw materials?

Answer: Much of the chemical industry as we know it today, both technically and economically, is based on ample supplies of fossil fuel raw materials. The very substantial known reserves of these materials, however, coupled with the adaptability of the chemical industry to changing circumstances would seem to indicate that any program of intentional limitation is unwarranted. If such limitation were unduly restrictive as to other fossil fuel uses, not only would this result in dislocation of other segments of the national economy, but it might react adversely on the economic base of the chemical industry as well. It may also be observed that the now established trend to wider application of nuclear fuels will of itself tend to conserve fossil fuels.

Answers to Question by Representative Weston E. Vivian During the Hearings (See p. 410, Vol. I)

Question: Do you find any place where joint sponsorship is desirable between the Federal Government and industry, such as pilot-plant operations?

Answer: In our prepared statement we mentioned approvingly "government-industry cooperative investigation," and would construe this to embrace jointly supported projects, also, where there is a mutuality of interest. In some instances this might be brought to bear at the pilot-plant stage; in others, either earlier or later stages of development might be logical for such consideration, depending on the nature of the research involved.

Response to the Remarks of Representative James G. Fulton During the Hearings (See p. 411, Vol. I)

It is regrettable that Congressman Fulton misunderstood the basic premises of our statement at several points, and we welcome this opportunity for appropriate clarification and reemphasis.

The chemical industry is committed to the desirability of preserving natural resources that have not been abused as well as restoring those which have been abused. It is incontrovertible, however, that many processes essential to the sustenance of life produce waste products for which there is no repository but the environment. Nevertheless, if esthetic values and beneficial uses of the environment are not impaired incident to such disposal, then there is neither measurable injury nor recognizable pollution.

In recommending that interim objectives be set at conservative levels, we primarily had in mind the situation where existing contamination is already in excess of anticipated quality standards. We would not propose to intentionally set requirements so loose that injury to esthetic values or beneficial uses would occur or be continued. Still, it must be recognized as current fact that a clear definition of acceptable quality for various environmental uses is not now known. Accordingly, the derivation of quality objectives for any given situation must perforce rely to a considerable extent on expert opinion and judgment, weighing the requirements of what may be competing beneficial uses. If requirements go beyond those necessary to safeguard esthetic values and beneficial uses, the cost of meeting them may be, and in many instances certainly would be, unnecessarily expensive without compensating tangible benefits. Experience and changing circumstances may indicate the desirability of either stiffening or liberalizing controls, and the avenue to modification should remain open.

Uniform regulation is an illusory concept. One has only to contrast a large installation on a small stream to a small installation on a large stream to illustrate the lack of logic in having the same waste controls apply to both. Further, no matter what is permitted (short of complete prohibition), an unsatisfactory condition could result from too many separate installations located near one another. The notion is further confounded by wide differences in natural water quality and in the relative priority of various beneficial water uses from one locale to another.

Responses to Questions of the Subcommittee on Science, Research and Development by the Tennessee Valley Authority

Question 1: What would be your views on a demonstration bringing certain TVA electric generating plants and the chemical plant to an essentially nonpolluting status, regardless of cost, with present technology?

Answer: We would be glad to see certain TVA electric generating plants and our chemical plant used as demonstration facilities to develop pollution control methods as fully as possible. It is important to recognize, however, that present technology, even if costs should be disregarded, will not produce what the committee has described as an "essentially nonpolluting status" for all elements of operations of this kind. For some of the pollutants, further technology must first be developed.

In the case of coal-fired electric generating plants, the air pollutants involved are particulates and sulfur dioxide. The technological problem with respect to removal of particulates has been solved. This is not true of sulfur dioxide, however. Several recovery processes which would remove 80 to 90 percent of the sulfur dioxide are presently under consideration and development, but further pilot plant testing of these processes is necessary before a full-scale demonstration of any of them could be usefully undertaken.

Sulfur dioxide recovery has been subject to reviews by many different groups in and outside the United States within the past few years, and one or more of the processes so far studied may prove eventually to be technically feasible. The U.S. Public Health Service is planning to evaluate the processes which presently appear most promising by arranging for the construction of small-scale demonstration or pilot plants at which they can be applied and tested. TVA has agreed to cooperate by making one of our coal-fired electric generating plants available for the installation of some of these pilot plants. We have a meeting scheduled with the Public Health Service later this month with regard to selection of the processes to be used. Operational experience with these plants would provide information which is essential to the design and construction of equipment for full-scale application to large power units. As soon as a workable solution has been found, we would be glad to proceed with a demonstration involving such full-scale application to a large power unit.

At TVA's chemical plant, as pointed out by our witnesses in their testimony before the committee, we now have underway a multimillion-dollar program for improved pollution control. This program, which is scheduled for completion by the end of fiscal year 1968, will achieve very high standards. These standards are regarded by experts as more than adequate but they will not render the plant entirely pollution free.

The TVA chemical plant is basically a research facility. We are continually dropping old processes and facilities and adding new ones, and we cannot now be certain what the pollution problems in connection with future facilities and processes will be. In the case of some existing operations, present technology leaves a number of problems to be solved to achieve "essentially nonpolluting status." We believe these problems can be overcome, although to do so might require replacement of some facilities. We cannot now estimate the costs which would be involved, but they would undoubtedly be substantial.

We would be glad to undertake a demonstration along the lines envisaged by the committee, but could do so only if we were provided with the necessary funds.

Question 2: How much of a "pollution abatement credit" would the best SO_2 removal process require today in order to sell the byproduct sulfur or other chemicals competitively?

Answer: As indicated in the answer to question 1, present technology leaves many questions unanswered, and we believe that the testing of small scale plants is necessary before answers can be provided. It is not possible, for example, to identify at the present time the "best" process for recovering SO_2 from power plant gases or to predict costs with accuracy. Subject to these reservations, we have averaged some very rough estimates made for what are generally regarded as the three leading processes for the recovery of sulfur dioxide from coal-fired generating plants, based on the present state of technology with respect to these processes. On this basis, we estimate that at a 1,000 megawatt coal-fired steam-electric generating plant, about 80 percent of the sulfur dioxide could be captured to produce about 700 tons per day of sulfuric acid, assuming full round-the-clock operation of the generating plant for that day. We further estimate, also on a very rough basis, that the cost of producing the sulfuric acid would be in the neighborhood of $25 per ton, and that it might be sold under contracts covering the large quantities involved for perhaps $16 per ton under present conditions. Obviously, there are many uncertainties surrounding these estimates. For example, if sulfuric acid were to be produced at a large number of coal-fired generating plants and offered for sale, the market for it would be glutted and the price would decline.

APPENDIX 2

PREPARED STATEMENTS SUBMITTED TO THE SUBCOMMITTEE ON SCIENCE, RESEARCH, AND DEVELOPMENT

STATEMENT SUBMITTED TO THE SUBCOMMITTEE ON SCIENCE, RESEARCH, AND DEVELOPMENT BY RAY K. LINSLEY, EXECUTIVE HEAD, DEPARTMENT OF CIVIL ENGINEERING, STANFORD UNIVERSITY, AUGUST 3, 1966. (ORIGINALLY SCHEDULED TO TESTIFY; UNABLE TO DO SO DUE TO AIRLINE STRIKE)

I am pleased that I have been invited to come here and discuss with you the question of the adequacy of technology for pollution abatement. It is such an all-encompassing subject that it is hard to know where to begin and what to say in a limited time. My problem is made no easier by the very excellent report of your research management advisory planel which has discussed the subject wisely and well.

A few weeks ago, in testimony before the Senate Committee on Interior and Insular Affairs, I suggested that one of our problems in looking at water today is that we are in a period of rapid transition. After centuries of slow change, we now find it difficult to realize that very major shifts in thinking are necessary. Unlike many other scientific and technological developments which have come upon us in a very short time, pollution problems have been developing very slowly for a long time. Our fundamental approach to the pollution problem is as ancient as man himself. Man started to pollute the atmosphere when he first learned to make fire. He piled his solid waste in great heaps which today, all over the world, mark the location of his ancient cities. He found that water was a very convenient medium for carrying away his wastes, and he learned to wash all manner of things in a stream. Ancient man could successfully employ these rather crude means of waste disposal because of his own very limited numbers. The quantity of waste produced was relatively small compared to the assimilative capacity of the environment. Today, when the annual population increase of the world exceeds the total population at the time of ancient man, the situation is quite different. Not only are there more people producing waste, but the per capita production is greater. In addition, our technology is producing substances which, when they become waste, are more durable than much of the organic waste of ancient man.

Sewers to transport storm water from cities date back into antiquity. Because of the prevailing practice of throwing refuse into the streets these sewers carried at least some of the waste washed into them by rain. It is only a little more than 100 years ago that direct sanitary connections to sewers were begun in major cities. These connections together with a system of refuse collection removed the waste from its highly visible location in the streets and considerably augmented stream pollution. As stream pollution got worse, plants for partially treating the sewage were designed to reduce the pollution load on the streams. Today we find that in areas of high population density the partial treatment of waste is not always adequate. We are also beginning to realize that we can ill afford to use so much water to dispose of this waste.

What I have just said can be restated to say that we are beginning to realize that we have a complicated system on our hands. Burning solid waste adds to air pollution as do the gases emitted in sewage treatment. Sewage may destroy the usefulness of a water supply. The automobile, a transportation device, is a major source of air pollution. Irrigated agriculture adds salts to the rivers. Pollution management clearly requires more than the concept of "put it where it won't be seen". We must study all our activities in the light of their total impact on the environment.

Science has a principle called conservation of matter. In essence, this states that matter cannot be destroyed. It may be converted into other forms, but its essential elements remain. We would not be far wrong if we drew from this a principle of conservation of pollution which said that waste materials, once produced, are with us always. With the exception of that relatively small fraction of waste materials which man reclaims for his own use and the portion of the waste materials which are converted by natural processes into useful material, the principle of conservation of pollution is essentially valid. When man burns solid waste, he does not eliminate it, he merely converts it to gases and particulate matter which may pollute the atmosphere. If we dump pollutants in the ocean, we are not eliminating them, we are simply putting them where we cannot see them. Conventional sewage treatment removes a portion of the pollutants from the water being treated, but these pollutants are not destroyed. In part, they are converted to less obnoxious gaseous or liquid forms which are discharged through the atmosphere or to a water body. In part, they remain as solids which must be "disposed of" in some way. When we bury solid waste in a sanitary land fill, it disappears from view, but it is still there. Water moving through the fill may leach material from the waste and carry it to the ground water or to another stream for years after the original disposal.

A few cities are now requiring every home to have a garbage grinder. This greatly eases their problem of garbage collection, but at the expense of increasing the magnitude of their sewage treatment problem. Solid waste is being changed to stream pollution. This may indeed be the most economic solution for the individual city, but what of the cities downriver whose water is more polluted? Applying salt is an effective means of snow removal from roads and streets, but melting snow and rain must eventually carry this salt to a stream or the ground water.

It is probably true that conventional means of dealing with pollution could, if pursued with vigor and sufficient funds, provide a short term solution to our problem. That is to say, a substantial investment in present technology might alleviate our problems for a few years. Not only would the expenditure be very large, perhaps more than we can really afford to pay, but such an approach might have another most undesirable effect. It could lull us into believing that we have the situation in hand, as we have been lulled in the immediate past. If this led to a failure to prosecute an effective research program on new technology, we would eventually find ourselves in a position which is even worse than our present one, but with nothing better by way of a solution. It is interesting to speculate where we might be today if we had recognized the environmental pollution problem in 1946 and had started to work on it at a rate of 10 percent of our expenditures on space research.

I have described our problem as a systems problem. Let me hasten to say that I do not suggest that this is the sort of systems problem that can be written down in mathematical expressions and answers derived in a few minutes or even a few hours time on a computer. I say this for two reasons. First, and foremost, we simply do not know enough about our problem to write the necessary expressions. Secondly, if we could write the necessary equations, there is every reason to believe that we do not have today a computer big enough to solve them. But a systems problem does not have to be solved by a mathematical equation and a computer. Basically, a systems analysis requires that we know something about the goals which we are striving for, and the capabilities and costs of solutions which would contribute to these goals. With systems analysis techniques, we would then seek to find the optimum combination of solutions for the attainment of our stated goals. Systems analysis requires an orderly, but not necessarily mathematical approach, to a problem.

If we wish to approach the pollution system realistically, we must do several things. These are:

(1) Define with reasonable accuracy the sources and quantities of pollutants now and estimate these data for future years.

(2) Identify the effects of these pollutants on man.

(3) Define with considerable clarity our goals for pollution abatement.

(4) Describe the technically feasible methods of dealing with each major pollution source with reasonable cost estimates.

(5) On the basis of the foregoing information, determine the most efficient combination of methods to deal with the problem.

There is little hope that we can or will deal with the total environmental pollution problem as a single systems analysis problem. It is too big and would take too long. Indeed, it may never be fully solved. New sources of pollution will develop. New abatement techniques will be found. The details of the problem will shift continuously. However, if we approach the problem systematically, we can hope that our efforts will yield the maximum possible achievement.

Pollution is the sum total of many different substances from many sources. The need for an inventory of these substances seems obvious, yet I know of no such inventory. Some pollutants are more harmful than others; some are easier to deal with. With a reasonably accurate inventory as a start we can begin to identify those substances and sources for which abatement offers the most immediate payoff. Because we are planning for the future we need estimates of future pollution sources and substances. Most important are some educated guesses at which substances, now nonexistent or unimportant, might be problems in the future. The problems which can be recognized in advance may never become problems. The inventory would seem to be a responsibility of the Federal Government and one which should proceed as rapidly as possible. In a sense it parallels the inventory responsibility of the Federal Water Resources Council, but the pollution inventory is a much more complex job than a water supply and demand inventory.

Item 2 of my list requires definition of the effects of various pollutants on man. This includes direct physical effects on health, economic, and social impacts, and indirect effects through damage to various ecologic communities.

Merely to secure this kind of information involves a major research effort. Reasonably precise determination of the public health impact of pollution is a major project because of the very large number of pollutants, the differing forms of pollution—air, water, and land—and the differing exposures to pollution. Clearly, however, if there is any element of pollution which is a health hazard, it must be eliminated. An understanding of the actual health hazards would provide a very positive goal with respect to certain pollutants. The ecologic impact of pollution is an even larger and more complicated research topic. The number of pollutants, the differing forms of pollution, and the differing exposures all remain and are compounded by the very large number of ecologic communities which need to be considered. The effects of pollution on fish involve considerably more than the mere poisoning of the fish themselves by direct contact with pollutants. Pollutants which in themselves would do no harm to fish may in some way break the food chain and seriously interfere with fish production. Even in evaluating the effect of a specific pollutant on fish, there are problems with respect to the young fingerling, the adult fish, the spawning fish, and fish egg, and so forth. A test made on a group of fingerling in a tank may not at all disclose the true impact of a pollutant which may not be sufficient to kill the fingerling fish, but which might in some way prevent the hatching of fish from their spawn.

A considerable body of information on the physical effects of pollution on man and his environment is available. One suspects that it needs to be organized and that this process would disclose gaps which need to be filled by systematic investigation. The economic impact of pollution is a relatively untouched problem area. Air pollution is known to damage certain crops. Is the crop loss suffered as a result of air pollution a significant cost to the Nation? Does it in itself justify the cost of air pollution control? Does it in combination with other losses justify the cost of air pollution control? Increased salinity of water imposes an additional cost on downstream users, both agricultural and industrial. How big are these costs? We have only yet begun to assess such factors. Economic factors may not be decisive in decisions on pollution abatement but they should certainly play an important role. The task of assembling this information should be relatively small as compared to other tasks in pollution abatement planning.

The debate on pollution control has strong esthetic overtones. People are offended by the appearance of a polluted stream or in some cases by the mere knowledge that it is polluted. To the extent these intangible factors enter our decisions, we need to know more accurately than we do how the public perceives pollution problems. Basically, we are all against pollution, just as we are against sin. But being against pollution and being willing to spend perhaps, a hundred billion dollars to effect a fairly slight visual change which would go unnoticed by most of the population may not be justified. We have many other uses to which $100 billion may well be spent. Quantitative procedures in the social sciences are less well developed than in other areas but the importance of this problem should make it an intriguing research area for the social scientist. In fact, I have an engineering student at Stanford who intends to do his doctoral dissertation on this very subject.

Once the inventory of pollution sources and evaluation of effects of pollution are complete it is necessary to move to step No. 3, definition of goals. It is easy to say that we wish to abate, mitigate, control, or eliminate pollution. What do these words really mean? We cannot return our air and our streams to a pristine purity which might have existed before man came to this world. Man is here to stay. He creates waste. Pollution is inevitable. We need realistic goals in terms of types and levels of pollution we will tolerate. These may be regional rather than national goals because of regional differences in environment. Whatever their form, a systematic approach to pollution abatement is impossible without them.

Having defined the problem and the goals, we need to know what techniques of abatement are available to us. It is here that we urgently need imagination and innovation. We already pretty well know what to expect of conventional techniques but what possibilities lie ahead in new methods of waste treatment? For example, toilet wastes and garbage which is passed through garbage grinders constitute a very large fraction of the organic pollution from the ordinary home (and require a substantial part of the water used in that home). Suppose these materials could be put into a sealed storage tank where they would not be obnoxious and from which they could be removed by a specially equipped truck and taken for composting. Such a system would have all the convenience of the present system to the householder, it might be simpler from the viewpoint of municipal garbage collection, it would minimize water consumption, and would achieve a separation from other forms of trash which might make processing of the other forms simpler. Such a system may be completely unsatisfactory, but we have never explored it and we do not know what it would cost. The substitution of electric motors for internal combustion engines could materially alleviate air pollution in urban centers. This is not a simple substitution. An entirely new system of transportation is involved. It does not appear to be beyond the realm of possibility, and in addition to alleviating air pollution, might also materially help in solving the traffic problem of urban areas and possibly make major contributions to highway safety. New technologies for more efficient removal of pollutants from water, for more efficient removal of pollutants from emissions of industrial gases, and so forth, are also clearly needed.

Perhaps more important than research and development to produce better means to treat wastes is a program to devise means to reduce the amount of waste which must be treated. New industrial processes which produce less wastes. Longer lives for everything from lampbulbs to automobiles. Containers and wrappers with minimum residual bulk when empty or which decompose more rapidly after use. A method of dealing with snow on roads that does not involve spreading tons of pollutant. Better use of fertilizers and pesticides so that none reaches the stream. An entirely new system for commuting in urban centers which does away with the internal combustion powered car. These are but a small sample of concepts which might be helpful in dealing with pollution. In most cases such solutions would help to solve problems beyond those of pollution.

The technological solutions I have suggested represent an area which industry might well press. The market is large and the returns could be quite attractive. In another area the Government may play an important part. The possibility of economic measures to stimulate pollution abatement has been pointed out by Kneese and others. Government incentives may also discourage a serious effort to seek new methods of meeting the pollution menace. Water from Federal reservoirs for dilution of wastes at no cost to beneficiaries, subsidies to water users which encourage water waste, subsidies to irrigation without recognition of the resulting saline pollution, and subsidies for construction of conventional waste treatment facilities all tend to encourage the status quo and discourage a new look.

Definition of problems and goals and discovery of possible abatement techniques would place us in a position to decide on the best approach to solve our problems. Here is the place for systems analysis, be it mathematical or skilled judgment. The techniques are less important than the facts.

I am not so naive as to believe that we will proceed step by step as I have outlined. Some of our problems are too urgent to brook delay. We cannot afford to stand still until new ideas are developed and checked out. I am also aware that it is fashionable to endorse research whenever a problem is faced. What I am really suggesting is planned research. Without research we cannot advance. Our research facilities and manpower are too limited to permit its reckless dissipation on random problems. We need to study the system we are coping with, to assess the most productive approaches and concentrate research and development effort where it can be expected to "pay off" most handsomely.

Statement Submitted to the Subcommittee on Science, Research, and Development by the Mill Creek Research Council, Inc., August 5, 1966

DEFICIENCIES IN RESEARCH CONCERNING THE MILL CREEK IMPOUNDMENT PROJECT

The Mill Creek Basin, a portion of Huron River watershed in southeastern lower Michigan, is under consideration by the Corps of Engineers as the site for a multipurpose impoundment project. If constructed this project would cost between $20 and $30 million. Its primary purpose would be low-flow augmentation, with other uses of water supply, flood control, fish and wildlife development, and recreation.

The site selected is in slightly rolling country and is a portion of a highly productive agricultural region. The topography would allow for a reservoir which would have an average depth of about 9 feet and when drawn down for flow-augmentation there could be as much as 6,000 acres of exposed earth. The storage capacity would be approximately 80,000 acre-feet, with 8,900 surface acres. The land acquisition would be nearly 16,000 acres.

The storage allowance for annual evaporation is 14,000 acre-feet, which is 2,000 acre-feet more than the storage capacity planned for supplementary water supply needs in the year 2000. This evaporation is equivalent of 4,591,600,000 gallons per year.

There are several smaller and deeper reservoir sites in the Huron River watershed which are in less productive land. These might be used singly or in combination to serve the needs of the community. However, under present laws which restrict the Corps of Engineers to multipurpose projects with "flood control benefits" these cannot even be evaluated by the corps.

The original plans for the reservoir are based on erroneous flow-rate statistics of the Huron River which established minimum flow at 21 cubic feet per second. Modern data, corrected to allow for leakage at dams and water pumped from the river for water supply, shows the minimum flow at more than 75 cubic feet per second.

The Michigan State Health Department required that a minimum flow of 50 cubic feet per second be guaranteed for the protection of the downriver communities if Ann Arbor and Ypsilanti were to expand their sewage treatment plants. It was indicated that this amount would provide a margin of safety for at least 20 years. At this time it is expected that water supply and sewage disposal services will be furnished from outside the basin. Yet the Corps of Engineers has made no attempt to reflect the errors by revising the storage requirements and is proceeding with the original concept which even before corrected data became available was a very much larger project than had been recommended as desirable or necessary by the Michigan Water Resources Commission and by Black & Veatch, engineering consultants.

The reservoir would impound runoff waters from a catchment area which is totally agricultural. Small ponds in the area are weed choked and produce quantities of algal growth. The water quality in this reservoir would certainly be affected by herbicides, pesticides, insecticides, and fertilizers, as well as animal wastes. Can these substances be defined as pollutants or is this term reserved for municipal and industrial wastes?

Will your committee attempt to establish such definitions and will it be concerned with the means of evaluating the effects of such materials in reservoirs prior to the construction of this type of impoundment?

What are the taste and odor problems that might be expected in water drawn from such an impoundment?

Do today's water treatment facilities have the means for coping with the chemicals used in modern agriculture?

What effect will agricultural nutrients have on the water quality in the Huron River itself as the waters are drawn from the reservoir?

And why does the Corps of Engineers gloss over this potential threat to water quality?

Will your studies also attempt to establish criteria for total land use? Or will water resources take precedence over all the others such as future food needs, green and open space requirements and ultimately even the space needs of the predicted megalopolis?

When the latter becomes reality the water resources of the Huron River Basin will be inadequate to serve the population regardless of a Mill Creek impoundment. In the future this area will participate in a metropolitan system of water supply and sewage interceptors because it is becoming impossible to confine ultilities and services within political boundaries. What assistance and guidelines can be drawn up to assist communities over the political hurdles when local sovereignty must be sacrificed for the well-being of residents of many communities?

The Bureau of Outdoor Recreation has been asked to add its plans for the reservoir to those of the Corps of Engineers. The cost-benefit figures are based on absolute maximum potential use of the recreational facilities which would be built into the area. Anyone who has ever lived in this portion of lower Michigan knows that there are numerous snowless days in winter and equally numerous cold and gloomy days in summer when recreational activities are nearly nonexistent; therefore, the use of the maximum is inaccurate and unrealistic.

For example, this is a low-snow-fall belt but Jerusalem Hill in the reservoir area, section 33, Lima Township, is predicted to draw 20,000 users per season for sledding, and tobogganing. Oldtime residents of the area can count on their fingers the number of times when this windswept hill has had snow on it and no snowmaking equipment is planned.

Bureau of Outdoor Recreation's drawdown plan calls for major drawdowns after Labor Day and into October. But are not the low flows most troublesome in the summer months when combined with hot weather? The Huron Clinton Metropolitan Park Authority states that drawdown at Kent Lake "is incompatible with park usage."

How can we determine prior to construction of this reservoir whether or not these conflicts can actually be resolved?

At least two candidates for graduate degrees in geography have resigned positions with Bureau of Outdoor Recreation in this district because they believed that proper research procedures are nonexistent. Yet the Corps of Engineers must accept the statistics as factual. Why don't social scientists devise more realistic formulas and guidelines for establishing accurate cost-benefit ratios?

The Bureau of Outdoor Recreation recommendations add 2,300 acres and $7 million to the initial cost of the project and the annual benefit they assign to the project is $1,626,000. However the annual agricultural loss of foodstuffs from this highly productive area has table value of $15 million. How can anyone justify the accrual of recreational and other "benefits" year after year without balancing them against the annual loss in food production? Is it accurate for the Corps of Engineers to ignore these economic factors?

There are at least six alternate sites in the Huron River watershed for impoundments. If impounding water for low-flow augmentation is necessary for pollution control will your studies provide formulas by which these sites could be studied?

The Corps of Engineers is limited by antiquated law to multipurpose projects which must include flood control. Therefore, it cannot furnish information relative to the possibilities inherent in one or more smaller single-purpose reservoirs, with or without importation of supplemental water, and/or interception of sewage effluents. If your committee can provide a guide for obtaining the necessary information to study these alternate sites some of the items which should be included are—

A. Volume of storage.
B. Surface acres of seasonal pool.
C. Land acquisition requirements.
D. Present land usage.
E. Character of catchment area.
F. Soil classification.
G. Present land ownership; that is, private or public.
H. Present land production and benefits.
I. Residual effects of present land usage on water quality.
J. Appraisal of the natural physical characteristics of a stream which could contribute to, or limit its usability for, various needs.

In addition, further and accurate information is needed to determine the following:

A. Amount of storage required with and without importation of water.

B. Amount of storage required with and without interception of sewage effluents.

C. Amount of storage required with both of the above, low-flow augmentation to improve the quality of lower Huron River for recreation and esthetic enjoyment.

Since it is predicted by responsible engineers that water importation and sewage interception is indicated probably by 1990, item C, above, becomes the most important and storage requirements should be calculated accordingly.

The lower Huron River because of its proximity to the Detroit metropolitan area can best serve as a source of pleasure and recreation for the people of the region if it is in an unpolluted condition. Water quality criteria should be established relative to the desired uses and effort must be made to achieve the chosen standards. Possibly the river could be safely used for swimming, boating, and water skiing, which uses are now prevented by Huron River Watershed Intergovernmental Committee's policy of 1960 enabling Ann Arbor and Ypsilanti to expand sewage treatment plants.

To illustrate this we quote the following:

> Mr. Rehard, who is chairman of the Supervisor's Inter-County Committee pointed out that the National Sanitation Foundation study presents some long term alternatives for both water supply and waste water disposal. It may be that the lower Huron River is more valuable to the bulk of the population in the Detroit Metropolitan Area for the matter of recreation than for waste disposal.[1]

The March 1966 report from the Fish and Wildlife Service concludes:

> The high fish and wildlife values attributed to this project (The Mill Creek Reservoir) should not serve to minimize the importance of existing high values of fish and wildlife of the lower Huron River and western Lake Erie. The low-flow augmentation made possible with this project, unless combined with the abatement of pollution at its source (Ann Arbor) could very easily result in a large increase of ineffectively treated wastes being dumped into the Huron River. Should this occur the Mill Creek Reservoir project could result in a net loss to fish and wildlife downstream from the reservoir.

The Huron Clinton Metropolitan Authority has obtained park sites on the banks of the Huron River between Ann Arbor and the river's mouth at Lake Erie. Obviously these sites would increase in value if the river could be used more intensively and the water quality improved.

The Metropolitan Regional Planning Commission complains in its recreation study, 1966, that the "disadvantage of the Mill Creek impoundment is its distance from the major center of population." Huron Clinton Metropolitan Authority's lower Huron River properties are much nearer and surely would be more frequently used.

In view of the foregoing it's difficult to justify the Bureau of Outdoor Recreation figures.

Is it possible that your committee can devise more realistic methods of establishing values?

Would stricter pollution controls at the sources, tertiary treatment, or interception of effluents furnish greater total benefits than flow augmentation to dilute the wastes in the river?

Before the construction of this reservoir is approved a number of alternative solutions should be considered. How can local governments and citizens obtain sufficient accurate information to present the community with choices? For example:

1. Recommendation of the National Sanitation Foundation for long range greater metropolitan area water supply and sewage interceptor system under the management of the Detroit Water Board. These studies were directed by Abel Wolman, Lewis Ayres, Richard Hazen, George Hubbell, and Louis Howson and give the most completely documented and thorough analysis of the problems of the area, indi-

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[1] Huron River Watershed Council, executive committee minutes, May 5, 1966.

cating that after 20 years or so Ann Arbor and Ypsilanti will outgrow the capacity of the Huron River for either water supply or waste water disposal.

2. Consideration of whether smaller reservoirs used singly or in combination for flow augmentation and recreation. The reasons for rejecting the Seneca Dam on the Potomac in favor of several small reservoirs as presented in the Department of the Interior report to the President, January 1966, may be relevant here, and the "pretty little lakes" might be much more valuable.

3. Exploration of ground water resources.

4. Examination of various methods of tertiary treatment and the possible applications in this situation. Technology is growing so rapidly that with new methods of treatment, low-flow augmentation for dilution of wastes may be unnecessary in the not too distant future.

5. Analysis and elimination of pollutants at their sources.

6. Evaluation of pumped storage reservoirs as conceived by Clarence Velz for other midwestern regions where good reservoir sites are unobtainable.

How can the public attack the problem of determining which of these methods will benefit the greatest number of people?

Would the National Sanitation Foundation recommendation if developed with tertiary treatment provide a greater control over effluents flowing into Lake Erie? At what point will the Huron River cease to be able to assimilate the wastes from the treatment plants?

Have scientists found specific gages for estimating when these critical points will occur?

The flood control, which is the means of entry for the Corps of Engineers into the Mill Creek project is now acknowledged to be less than 5 percent of the project's "benefits." It is also apparent that flood control devices (channel straightening, widening, and dikes) can be constructed in and around Flat Rock where the floods occurred 25 years ago.

We anticipate that the corps will conclude their study in the spring of 1967, and we have been chided for not awaiting that report before raising the questions and issues which concern us. However, we believe that if the corps requires several years and many dollars to make its study, those who have to evaluate it certainly need a few months to gain at least some of the basic information. Without such information intelligent decisions will be inconceivable. It is becoming evident that in spite of the money that has been spent, obvious deficiencies and inaccuracies remain which indicate that the conclusions to be reached may be worth very little.

Is it possible for local governments and the citizens they represent to end a project begun by the Corps of Engineers if they believe it is not in the best interests of the community as a whole?

Or is it a fact that once the Corps of Engineers is involved in a project, the decisionmaking stage is complete?

Since the decision to build the dam is irreversible it is vital that every care be taken to insure that the decision is a correct one.

To summarize we review the following:

(1) Flow-rate statistics used by corps were in error.

(2) Disposal of waste water in the Huron River works a hardship on the downriver population.

(3) The character of the runoff to be impounded would be detrimental to water quality.

(4) Alternatives as recommended by the National Sanitation Foundation are available.

(5) Bureau of Outdoor Recreation report is inaccurate and misleading.

(6) The Fish and Wildlife Service report is unenthusiastic.

(7) Alternate reservoir sites are available and have not been studied.

(8) Future land use requirements of a growing metropolitan region have not been considered.

(9) Future food needs of this population have not been considered.

(10) Thirty million dollars spent for the Mill Creek Reservoir would provide only a stopgap solution, because by 1990 Washtenaw County will need supplemental or alternate primary water supply and waste disposal facilities.

We have submitted questions relative to a specific situation in hopes that scientific procedures can be directed toward specific solutions. We are sure that similar problems exist across the country and we hope your work will begin to resolve them.

Therefore in view of the foregoing we hope your committee will attack the problem of furnishing adequate scientific information and proper scientific procedures for evalution of such projects before they are built. Only in this way can the public be protected from tragic and very expensive mistakes.

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STATEMENT SUBMITTED TO THE SUBCOMMITTEE ON SCIENCE, RESEARCH, AND DEVELOPMENT BY BURR ALLEGAERT, INTERNATIONAL PIPE & CERAMICS CORP., AUGUST 8, 1966

Knowing of the current hearings being conducted by the Subcommittee on Science, Research, and Development into the adequacy of technology for pollution abatement, we should like to bring to the committee's attention for inclusion in the record certain brief excerpts on this subject from a recent special issue of the Interpace Technical Journal.

International Pipe & Ceramics Corp., of Parsippany, N.J., publisher of this periodical, invited leading authorities to write on several aspects of the overall water resources development and pollution abatement problems.

We feel that the following passages are especially pertinent:

John E. Kinney, sanitary engineering consultant, Ann Arbor, Mich.:

> Questions such as "What is the best way of augmenting our present municipal water source?" "How must we organize our pollution control administration?" "What is pollution?" demand specific and detailed answers for each individual situation. Slogans will not substitute for sound judgment, nor will mass misunderstanding bring about rational results.
>
> But research for adequate and valid data is forgotten when a proposal is being argued in the public forum. Details become unimportant because of the graveness of the issue. Even basic circumstances are lost sight of, such as the principal fact that we are not running out of water. We have, at best estimates, underground water at shallow depth equivalent to 34 times the annual runoff from all our rivers. There is probably an equal volume in deep storage.
>
> The "running out of water" hysteria is nurtured by the assertions that while our present water consumption is 300 billion gallons per day, it will rise by 1980 to 600 billion gallons per day, and that our potential total supply is only 515 billion gallons per day. Doubling our usage in 15 years is an optimistic forecast of growth, to say the least, but it permits the forecast of a national shortage. This deficit prompts the gloomy prophecy that we must resign ourselves to a future of existing on "used" water.
>
> The fallacy is twofold:
>
> > Water used is not water consumed. Of the 300 billion gallons per day now used, only about 60 is consumed [not available for reuse]. Most of this loss is via agriculture.
> >
> > We are now reusing water. In fact, we are now using the same water as was used in Biblical times. And in areas such as the Cuyahoga, the Mahoning, and the Monongahela Rivers, we are pumping several times as much water as is carried by the river during dry weather. If that is not enough to destroy the myth, we now use 2,000 billion gallons per day for hydroelectric generation—four times our estimated future potential supply.

James F. Wright, executive director, Delaware River Basin Commission, Trenton, N.J.:

> Let us now consider some similarities and differences between industrial and municipal wastes, which together comprise our water quality management problem. From this we may be able to guess where we will be going in the next decade.
>
> In terms of volume, the industrial waste input in the Delaware estuary—from Trenton to the sea—is roughly equal to the load imposed by municipalities. This means that probably for the foreseeable future reductions of the industrial waste load will take at least as much effort as municipal control.

Trends in the quantity of process water used per ton of product indicate a reduced ratio, which is to say that industry in general is working hard toward cutting water demand and waste output. Per capita use of municipal water supplies, conversely, is still on the increase. However, as our society grows, not only in numbers but in complexity, our industrial effort moves at a faster rate than our population. Thus it seems reasonable to assume that the problem of the future will continue to reflect a rough equivalency of industrial and municipal waste loads. A radical change in proportion does not appear likely.

H. Dewayne Kreager, consultant to industry, Seattle, Wash.:

Water management starts with sound standards of pollution control. Only relatively pure water can be used again and again. And our water shortage problems can never be solved unless we can use present supplies many times over. This multiple reuse requires water quality standards that are compatible with the greatest number of reasonable water uses in an area and commensurate with public health, but not necessarily permissive of all water uses possible in an area.

Industry needs standards that can be administered, that are administered, and against which industry can measure its own performance or judge its risk in further capital investment.

There remains the problem of paying for these water management programs.

These national public interest aspects of water management suggest that another requirement for solving the Nation's water problems at a reasonable cost is an incentive for water purification by private industry as well as government. The conclusion seems logical that to supplement public expenditures for water purification, water movement, and water management, the principles of rapid tax amortization or the investment tax credit may well be used to stimulate private capital investment in required water pollution abatement facilities.

We have tried through this special issue of the Interpace Technical Journal to advance the understanding of problems that must be solved in pollution abatement and water resources development. We hope that the committee will find it helpful and informative in their current deliberations.

STATEMENT SUBMITTED TO THE SUBCOMMITTEE ON SCIENCE, RESEARCH, AND DEVELOPMENT BY DR. RENE DUBOS, THE ROCKEFELLER UNIVERSITY, AUGUST 9, 1966

The following statement appears on page 9 of the Advisory Panel's report on The Adequacy of Technology for Pollution Abatement:

> No evidence has yet been produced that low levels of pollution have unfavorable effects on human health.

Similar skepticism concerning the potential health dangers of air pollution has been expressed elsewhere by Prof. A. Wolman. In his usual pithy manner, Professor Wolman suggested that air pollution is principally an "esthetic affliction."

> If exhaust gases emitted by a diesel bus had a fragrant aroma, or worse yet, led to physiological addiction, not many people would complain about traffic fumes.

There is no doubt unfortunately that air pollution is more than an esthetic affliction, and that it always results in various forms of physiological suffering and economic loss. How then to account for the statement made by Professor Wolman? a statement which is the more surprising because he is such a great scholar and has associations with Johns Hopkins University and its prestigious school of medicine and public health.

The reason for the failure to demonstrate convincingly the dangers of environmental pollutants is that biomedical scientists have become conditioned to regard as really valid only the type of information they can derive from orthodox laboratory techniques. This attitude has led them to emphasize the pathological effects that occur rapidly and that are the manifestations of fairly direct and clear cause-effect relationships. Admittedly, the effects of environmental pollutants are not very impressive in this light. In fact, one might well gain the impression that air pollution is of no consequence because experimental animals and probably human beings also readily develop tolerance and even cross tolerance to the acute injurious effects of a variety of irritating substances.

The dangers to health posed by the usual levels of environmental pollution, and of air pollution in particular, are not readily detected because they are always delayed and often extremely indirect in their mechanism. Indeed, as already mentioned, exposure to low levels of certain air pollutants induces tolerance against the acute toxic effects of higher concentrations; but this very tolerance produces various types of tissue damage and other chronic pathological effects that become noticeable only later in life or even in subsequent generations.

The industrial areas of northern Europe provide an informative example of the delayed dangers of environmental pollution.

Ever since the beginning of the Industrial Revolution, the inhabitants of northern Europe have been heavily exposed to many types of air pollutants produced by incomplete combustion of coal and released in the fumes from chemical plants; such exposure is rendered even more objectionable by the inclemency of the Atlantic climate. However, long experience with pollution and with bad weather has resulted in physiological reactions and living habits that have adaptive value. This is proved by the fact that northern Europeans accept almost cheerfully their dismal atmospheric environment even though it appears almost unbearable to outsiders who experience it for the first time.

Adaptive responses to environmental pollution are not peculiar to northern Europeans. They occur all over the world in the heavily industrialized areas whose inhabitants function effectively despite the almost constant presence of irritating substances in the air they breathe. It would seem therefore that human beings can readily make an adequate adjustment to massive air pollution.

Unfortunately, acceptance of air pollution results eventually in various forms of physiological suffering and economic loss. Even among persons who seem almost unaware of the smogs surrounding them the respiratory tract continuously registers the insult of the various air pollutants. After periods of time that differ from one case to another, the cumulative effects of irritation commonly generate chronic bronchitis and other forms of pulmonary disease. Because this does not happen until several years after initial exposure, it is difficult to relate the pathological condition to the primary physiological cause.

Chronic pulmonary disease now constitutes the greatest single medical problem in northern Europe, as well as the most costly; it is increasing in prevalence at an alarming rate also in North America, and it will probably spread to all areas undergoing industrialization. There is good evidence, furthermore, that air pollution increases the incidence of various types of cancer as well as the numbers of fatalities among persons suffering from vascular diseases. But here again, the long and indefinite span of time between cause and effect makes it difficult to establish convincingly the etiological relationships.

The delayed effects of air pollutants constitute models for the kind of medical problems likely to arise in the future from other forms of environmental pollution. Allowing for differences in detail, the course of events can be predicted in its general trends.

Wherever socially and economically convenient, chemical pollution of air, water, and food will be sufficiently controlled to prevent the kind of toxic effects that are immediately disabling and otherwise obvious. Human beings will then tolerate without complaints concentrations of environmental pollutants (whatever their nature and origin) that they do not regard as a serious nuisance and that do not interrupt social and economic life. But it is probable that continued exposure to low levels of toxic agents will eventually result in a great variety of delayed pathological manifestations creating much physiological misery and increasing the medical load. The point of importance here is that the worst pathological effects of environmental pollutants will not be detected at the time of exposure; indeed they may not become evident until several decades later. In other words, society will become adjusted to levels of pollution sufficiently low not to have an immediate nuisance value, but this apparent adaptation will eventually cause much pathological damage in the adult population and create large medical and social burdens.

It is well known, for example, that highly effective techniques have been developed to control the acute diseases that used to be caused by water pollution. Microbial pathogens can be held in check by chlorination; organic matter content can be minimized by dilution, oxygenation, and other chemical techniques; and of course water can be made limpid by filtration. But there is no practical technique for removing inorganic materials, as well as some synthetic organic substances, that tend to accumulate in water supplies as a result of industrial and domestic operation. Even though clear and free of pathogens, many sources of potable water are now becoming increasingly contaminated with a variety of chemicals that probably exert delayed toxic effects. In this regard, it is worth keeping in mind the recent reports suggesting that the incidence of certain forms of cancer and vascular diseases is correlated with differences in geological formation and in the mineral content of water supplies. While these reports are still preliminary and sub judice they point to a new kind of threat, which though ill defined, bids fair to become of increasing importance in the future.

In my opinion, the medical problems posed by environmental pollution will require a kind of scientific research which is greatly neglected at the present time, and for which adequate facilities do not exist either in medical schools or in research institutes.

For example, it will be necessary to maintain and study various kinds of experimental animals under a wide range of conditions for prolonged periods of time, and indeed for several generations. To be successful such studies will have to be carried out with animals of known genetic structures and experiential pasts. Equipment will be needed to record, retrieve, and analyze the complex data to be derived from the study of large populations and multifactorial systems.

The mere listing of these facilities points to the need for new types of institutions with a special organization of highly integrated personnel. What is required is nothing less than a bold imaginative departure to create a new science of environmental biomedicine.

Unfortunately it will always remain impossible to predict from laboratory experiments all the threats to health that can arise from technological innovations. Unforeseeable accidents will happen, as was the case with exposure to ionizing radiations or with chain cigarette smoking, or with the use of thalidomide during the first 3 months of pregnancy. Since it is impossible to test all the effects of all technological innovations, some of them will inevitably have pathological consequences.

We must abandon, in fact, the utopian hope that regulations can protect us completely from all health dangers in the modern world. For this reason, the science of environmental biomedicine should be complemented by a prospective kind of epidemiology, designed to detect as early as possible early manifestations of abnormality in the population at large so as the guide efforts to trace such abnormalities to technological and social changes. Seen in this light, prospective epidemiology would constitute a kind of protective social organ, as assential to disease control as are the safety regulations designed to protect the public against known dangers.

Statement Submitted to the Subcommittee on Science, Research, and Development by Alex Radin, American Public Power Association, August 10, 1966

ELECTRIC VEHICLES AND AIR POLLUTION ABATEMENT

The motor vehicle commonly is described as a major source of air pollution. A report by the Department of Health, Education, and Welfare, published last November, estimated that about half of the total air pollution problem in the United States is caused by cars, trucks, and buses. A report published in June in St. Louis, Mo., indicated that 63 percent of the hydrocarbons discharged into the atmosphere in that city during a 1963 test period were attributed to automobiles.

Efforts are being made to control the exhausting of hydrocarbons and carbon monoxide by vehicles, but even the best of these provide something less than 100 percent control. For example, 1966 auto models for sale in California, where a stringent exhaust control law is in effect, are equipped with exhaust control systems that reduce hydrocarbon emissions by about 65 percent and carbon monoxide emissions by about 50 percent, according to the HEW report.

A PERMANENT SOLUTION POSSIBLE

On this basis, even the adoption of California-type legislation by all of the other States would not solve the vehicular pollution problem; it would merely permit a doubling of the number of automotive vehicles without any increase in the present level of pollution, admittedly too high. Population projections indicate that a doubling of the number of vehicles can be anticipated within a relatively few years, and automotive pollution will rise accordingly.

Members of the American Public Power Association are deeply interested in what appears to offer a solution to a major part of the automotive pollution problem—the electric battery-powered vehicle. Although it is not likely that battery-powered automobiles would completely replace combustion-powered vehicles, the air pollution problem would be materially alleviated by the widespread use of battery-powered automobiles and trucks.

Development of new types of batteries which are lighter in weight and more long lasting than earlier types has stimulated much interest in the battery-operated vehicle. Our association has established a new committee to promote the electric auto. Battery-powered forklift vehicles, golf carts, delivery trucks, and other specialized vehicles are beginning to catch on, particularly in Great Britain.

The early development of the automobile proceeded along three principal routes—the gasoline-powered engine, the steam engine, and battery-driven electric vehicle. Some of the early manufacturers switched from one type to the other; all types had certain advantages.

SIMPLICITY AND RELIABILITY NOTED

A description of the battery-powered automobile of the turn of the century indicates that it had reached an enviable position. "Evolution of the American Automobile," by Daniel D. Gage and Anne C. Garrison in Business Topics, published by Michigan State University, Autumn 1965, notes that—

> It was the ultimate in simplicity and reliability, starting immediately with the turn of a switch, moving silently, increasing speed with utmost smoothness. Anyone could learn to drive it with finesse in five minutes. Consequently, it became identified with lady drivers and older people who were not concerned with dash and dreams of glory. Like its upholstery, its public image was dove grey. Its top speed did not exceed 25 miles an hour, and its range was limited by the need for recharging the storage batteries every 60 miles, either at a public garage or by means of expensive home equipment. As a passenger car, the electric car held on until the first World War, but the electric truck for street or in-factory use was revived 25 years later.

The same article notes that after the gasoline internal combustion powerplant won out over steam and electricity—

> For over half a century engineering ingenuity has been devoted to improving the piston engine, which is basically an over-elaborate and unsatisfactory source of power. It may have been the challenge of perfecting this imperfect machine attracted designing talent to it rather than to the steam or electric car.

RESEARCH EFFORT NEEDED

Whatever its merits as a source of automotive propulsion, the gasoline engine is choking our civilization with its fumes. While continuing to perfect this "overelaborate and unsatisfactory source of power" to diminish its contribution to our air pollution, it would be desirable, also, to devote engineering talent to the battery-driven vehicle, which appears to have many uses in our urbanized society today.

A study by the Cornell Aeronautical Laboratory, Inc., at Buffalo, N.Y., last year, made for the Commerce Department, suggested the desirability of two distinct types of vehicles, one for urban use and one for interurban highway travel. The Cornell group predicted that a major market for electric automobiles, primarily for urban use, will appear by 1980, pointing out that the electrically powered car creates no air pollution and, perhaps more persuasive to potential buyers, has operating costs which are considerably less than those with internal combustion engines for stop-and-go driving.

Just recently, an interesting suggestion was made by Columnist Howard K. Smith in the June 1966 issue of Washingtonian magazine. Declaring that there are dozens of things which we can do about city traffic "when the moment of total paralysis and the incidence of lung and throat ailments finally prove that something must be done."

One of these could be to provide inner city drivers with a fleet of drive-yourself electric, two-seater carts, which could be driven for a mile, at a speed of 20 miles per hour, for each coin put in a slot. "There would be no fumes, no important accidents, and no traffic jams caused by a mere 40 or 50 people scattered 1-apiece in limousines big enough for 8."

CADILLACS VERSUS HORSES

It is certainly true, as Mr. Smith says in the same column, that there are few inner cities today where distances were not covered faster half a century ago in horse-drawn vehicles than they are today in Cadillacs.

So one arm of the research effort into the electric vehicle can be directed toward designing, specifically for urban use, a vehicle which can transport people from place to place at relatively low speed, with ease of stopping and starting in dense traffic. The design of the vehicle itself requires an investment of talent and imagination.

Since there remain a good number of one-car families in America, and since the automobile represents both a convenience and a pleasure vehicle, a great deal of work must be done to increase the speed at which a battery-driven auto can travel, and to increase the distance which can be traveled without recharging the batteries.

A recent article by Edmund K. Faltermayer, appearing in the November 1965 issue of Fortune magazine, reported that Yardney Electric Corp. of New York City has fitted up a special Renault Dauphine with lightweight batteries that can propel it at speeds up to 55 miles an hour, and up to 80 miles on a charge. "The catch is that these are military-type silver-zinc batteries costing $3,000." Nevertheless, Mr. Faltermayer added, several companies, including Yardney and General Dynamics Corp. are pushing ahead in the search for batteries that would cost only a fraction of this.

Mr. Faltermayer concludes that while a battery-operated car suitable for long journeys is a long way off, a smaller version might be available in a few years. Perhaps he was overly pessimistic, in view of progress which could be made if an all-out research effort were launched to develop smaller, lighter, and more powerful batteries. The fuel cell may offer an even more promising field for further research.

FUEL CELLS HOLD PROMISE

William T. Reid, of Battelle Memorial Institute, who is serving as coordinator of a broad research program on fuel cells, declared in a recent article that the greatest promise in providing electrical power for an automobile comes from the fuel cell. Although fuel cells are not being used commercially, Mr. Reid reported that they are being used experimentally for powering forklift trucks, golf carts, and the like.

From the standpoint of electric utilities, Mr. Reid noted that the hydrogenoxygen fuel cell, which presently has reached the highest level of development of any type of fuel cell, would run on the products of electrolyzed water, thus opening up the possibility of an electrolyzer in each home garage, or in service stations in residential areas.

Batteries presently available cannot be used effectively in automobiles because they are too heavy and too costly, Mr. Reid said in the same article. But he suggested that improvements can be attained in lead-acid batteries—improvements which battery manufacturers have not been forced to make in the past because their present product meets the requirements of the present market. "Here is one area where research might make a major contribution," Mr. Reid declared. "Another would be research and development leading to a wholly new secondary battery based on one of the light metals such as lithium, sodium, magnesium, or calcium with a nonaqueous electrolyte." He added that this would be no easy task but, if successful, it would pay great dividends for other electrical storage systems as well as for electric automobiles.

Mr. Reid's article concluded that regenerative braking, traction motors specially designed for automobiles, controls, and auxiliaries all will need considerable development. In each of these areas, research could be justified leading to a final, practical prototype of an electric automobile.

NEW BATTERIES DEVELOPED

Within the past year, two new types of electric storage batteries have been announced. In December 1965, the Edison Electric Institute and General Dynamics announced a prototype zinc-air battery expected to be ready for testing soon. In February of this year Bulton Industries, Inc., announced the successful demonstration of a lithium battery that will be subjected to further development work. During the past decade, the traditional lead-acid battery found in every automobile and the industrial nickel-iron battery developed by Edison have been joined by the nickel-cadmium, nickel-silver, silver-zinc, silver-cadmium and mercury batteries. Developmental work also is going forward on sodium batteries.

An article on developments in electrochemical energy-conversion devices, batteries, and fuel cells, by Dr. M. Barak of Chloride Technical Services, Ltd., Swinton, Manchester, England, summarized recent progress in England, where battery-powered delivery trucks are extensively used, and where passenger vehicles are being designed for battery operation.

Dr. Barak concludes that development work must continue in the direction of lightweight fuel cells with higher outputs, lightweight traction motors, and possibly high-speed transmission before fuel-battery electric cars can become a practical reality.

He reported that over 100,000 electrically propelled vehicles are in operation in Great Britain, including industrial trucks used to transport materials and products in factories, commercial vehicles, mining locomotives, and so on.

A MILLION ELECTRIC CARS PREDICTED

The Electricity Council in Britain more recently predicted that within 10 years a million battery-driven automobiles will be in operation. There are four small electric cars being tested on London streets as a result of the Council's campaign to promote the electric vehicle—two British Motor Corp. "mini" cars, with the gasoline engine replaced by batteries and an electric motor, and two which are specially designed for electric operation by Scottish Aviation and Peel Engineering, according to a dispatch from London which appeared recently in the Chicago Tribune.

The Scottish Aviation model, called the Scamp, and the Peel car, called the Trident, are expected to cost less than $1,000 when mass produced. They can go only about 30 miles between recharging, at a top speed of about 40 miles on hour. Batteries weigh about 700 pounds in the two-passenger models.

The Electricity Council predicted that eventually parking meters will be wired to recharge batteries, although recharging would be done in garage sockets during night, using off-peak electric rates, in most cases.

It seems highly important to pursue the design of vehicles specifically for battery operation, as the British are doing. This approach may result in vehicles which are most suitable for specific uses; e.g., commuter travel to and from large cities, as well as in vehicles which make the most efficient use of battery power. Obviously the breakthrough to wide-scale use of electric vehicles will not come as a result only of fitting up standard model cars for battery operation. And a real breakthrough in terms of consumer acceptance must come if the battery-operated vehicle is to have an impact on the air pollution problem.

FEDERAL FUNDS FOR BATTERY RESEARCH

There are about 15 Federal agencies funding a total of 86 projects in battery research. Of these, 21 are being performed in Government laboratories, 14 are being performed by 10 universities, and 51 by 24 industrial companies. Manufacturing corporations also are conducting research.

The Tennessee Valley Authority purchased a battery-operated electric car in 1961 for study and evaluation of the possible electric utility load buildup that could occur from public acceptance of such a vehicle. The car is a Renault Dauphine, with electric motor and batteries substituted for the gasoline engine.

After a series of tests on the car, which is called the Henney Kilowatt, it was concluded that commercial feasibility of the electric car "must await a substantial improvement in performance capability, particularly in the capacity to travel longer distances." A need for "major advances in storage battery technology" was noted in TVA's report on the Henney Kilowatt, but it was pointed out that research being carried out in connection with the national space program could make such advances possible.

In 1961, the Lead Industries Association of New York launched a campaign to increase the use of storage batteries as a source of electric power for industrial trucks, personnel carriers, and other vehicles. The association estimated that the electricity consumption of a single electric industrial truck would be 7,500 kilowatt-hours per year, or more than 5 times as much as is used by a window air conditioner. This gives an indication of the importance of the electric vehicle to an operating utility, particularly when we consider that the bulk of the recharging load would come during the night, when other loads would be very low. Several electric utilities have launched sales promotion campaigns to sell electric trucks, according to an article in the August 23, 1965, issue of Electrical World magazine.

R. & D. SUPPORT REQUIRED

A leading proponent of electric autos to combat air pollution has been the Electric Storage Battery Co. The president of this firm, M. G. Smith, has called upon the President to "make recommendations for research and developemnt of all kinds of nonpolluting devices and spell out what both the Federal Government and private industry should do to get those devices built and used—universally and in the least possible time."

Mr. Smith declared that nonpolluting, battery-powered vehicles for low-speed, low-mileage urban transportation are feasible right now.

This brief summary of developments is not intended to be comprehensive, but merely to indicate that there is widespread interest in the electric vehicle and a recognition that it can substantially reduce the air pollution problem, if it is used as an alternative to the gasoline-powered car in urban areas.

Widespread use of electric vehicles would require increased generation of electric power in order to recharge the batteries of electric vehicles. In this connection, the question of air pollution from electric generating plants will be raised, and should be raised, in assessing the total impact of the use of electric vehicles on the pollution problem.

Unlike gasoline burning automobile engines, modern electric generating stations do not produce carbon monoxide, and the gas from stations is discharged into upper atmosphere, not at street level where it directly contaminates the air people breathe. Furthermore, utilities now have very sophisticated equipment for controlling pollution.

In general, it would seem easier to regulate the discharge from a few hundred large generating plants than from millions of automobiles. The trend toward construction of larger plants, in more remote locations, will facilitate the regulation of generating plant pollution. Increasing use of nuclear fuel also will reduce the potential pollution from generating plants.

The members of our association are fully aware of the pollution problem, as it is affected by the burning of fuels to produce electricity, and I am confident that they will cooperate in any reasonable plan to reduce or eliminate such pollution.

In addition to establishing a special committee to promote greater research which will lead to a "breakthrough" in mass markets and mass production of electric automobiles, our association, at its annual conference in Boston earlier this year adopted the following resolution by unanimous vote on May 12, 1966:

ELECTRIC VEHICLES

Whereas battery-powered passenger and other vehicles offer an alternative to vehicles powered by combustion engines, which create severe air pollution problems, and

Whereas research currently underway indicates that economically feasible battery-powered vehicles can be developed within the near future if the electric industry and manufacturers push forward with an aggressive program of research and development, and

Whereas the electric vehicle promises to provide an excellent off-peak load for electric utilities,

Now, therefore, be it resolved: That the American Public Power Association urges a large-scale research and development effort to bring the electric vehicle to the market.

APPA hopes that your committee, in attacking the most pervasive source of air pollution, will recommend the kind of large-scale research and development effort necessary to make available a pollution-free means of transportation for our urban areas.

Our association urges the committee's support for a two-pronged research and development effort. Such an effort would include both design of new vehicles suited for battery operation and development of lighter, longer lasting, and less expensive batteries which can power the vehicles of the future.

STATEMENT SUBMITTED TO THE SUBCOMMITTEE ON SCIENCE, RESEARCH, AND DEVELOPMENT BY GEORGE A. HOFFMAN, UNIVERSITY OF CALIFORNIA, AUGUST 17, 1966

ENERGY REQUIREMENTS FOR ELECTRIC AUTOMOBILES

(By George A. Hoffman, research engineer, Institute of Government and Public Affairs, University of California, Los Angeles, Calif.)

I. INTRODUCTION: WHY ELECTRIC AUTOMOBILES?

Automotive propulsion accounts today for about half of the energy generated by combustion in the United States. A review paper on the energy requirements of automobiles—particularly electrically driven cars—appears therefore to be appropriate for this first conference on energy conversion.

The internal combustion engine was not always the favorite energy conversion device for propelling passenger cars. At the turn of the century there were more battery-operated, electric motor cars in use in this country than either steam or gasoline powered. But the severe range and speed limitations of storage batteries in those days soon doomed the electric car for oblivion. Quantity demand and production of electric automobiles ended half a century ago.

But in the last decade or so some automotive trends specifically favorable to the reconsideration of electrically driven passenger cars have developed. For example:

Electric motor design has progressed very rapidly in recent years. Improvements in electromechanical conversion efficiency and in weight reduction are now at the point where the electric motor merits reinvestigation for automobile traction.

In the past decade, the weight of batteries and regenerative fuel cells per unit of stored energy has dropped to a small fraction of their value of a half-century ago.

The large increase in air pollution from the exhausts of the internal combustion engine has become a serious national problem. The socioeconomic losses due to degrading the quality of the air we must breathe might yet force installation of smog control devices on cars costing as much as the engine itself.[1] Battery-operated electric cars do not contribute significantly to air contamination.

The demand for cars per capita is increasing with a related proliferation in diversity of automobile models. The rate of increase is greatest for the second car in the U.S. family, used

NOTE.—The views expressed in this paper are those of the author. They should not be interpreted as reflecting the views of the institute nor of the university, or the official opinion or policy of the sponsors of this study.

[1] George A. Hoffman, "Los Angeles Smog Control," Rept. MR–56, Institute of Government and Public Affairs, UCLA, March 1966.

either for commuting or for household-type trips, and characterized by more missions than the first car, but of shorter range. These suburban cars appear the most readily adaptable to electrical conversion.

Consumer prices for gas and oil are rising proportionately faster than the price of electricity, and will do so for the foreseeable future. Electric propulsion of ground vehicles is therefore steadily becoming more attractive economically. Automotive energy conversion would be more efficient and operating costs cheaper if nonfossil electrically regenerable fuels were used.

For these reasons, the design of the electric car is reviewed here with estimates of its energy requirements.

II. GENERAL MAKEUP OF ELECTRIC AUTOMOBILES

Automotive marketing history shows clearly that it is almost impossible to successfully introduce a radically changed car to the motoring public if it departs too noticeably from the established demand and acceptance criteria of the time. To be popularly wanted, manufactured, and sold in large numbers, electric automobiles should conform to the major characteristics of conventional gasoline engine cars. This requirement spells out most of their basic design criteria.

Electric cars should therefore be engineered to resemble or excel present-day cars in most of the following respects:

General appearance and diversity of models;
Convenience, comfort, passenger capacity and protection, interior design;
Performance, top speeds;
Handling, agility, ride;
Range between refueling;
Costs, initial and operating.

After a century of development, the weight composition of automobiles has been dictated by the consumer to reflect the above six points and others. For the great variety of cars on the road today, ranging in curb weight (takeoff gross weight) from 1,500 to over 5,000 pounds, the weight composition is remarkably uniform, both as to proportions of weight and as to linearity with curb weight. Figure 1 is an illustration of the consistency of the weight ratios of major component categories of 1966 domestic and imported models, designed for the above set of criteria.

These ratios are listed in table 1 for 16 component subgroupings, and are the starting point for any successful design of electric cars. Basing the design on the ratios shown in table 1, assures that the driver at the wheel and his passengers perceive little difference in driving, or riding in, an electric auto versus a conventional car.

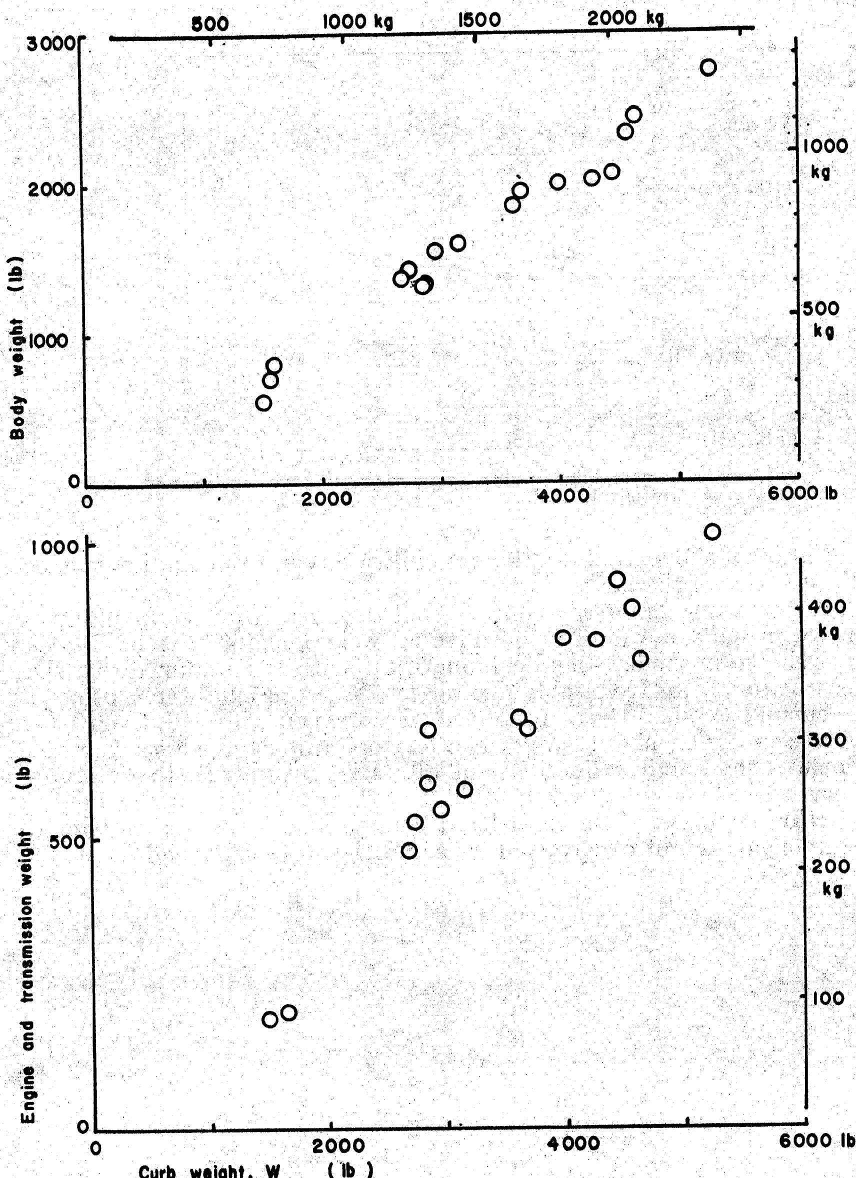


FIGURE 1.—Illustrative component weight versus total weight of 1966-model automobiles.

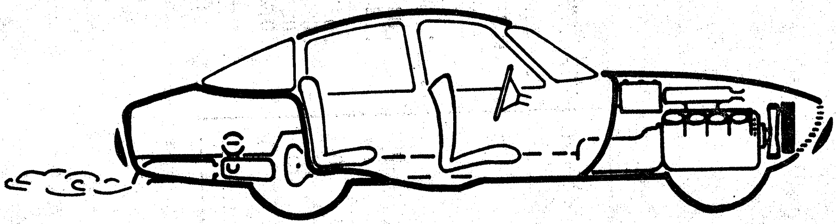
TABLE 1.—*Weight composition of modern automobiles*

Category and subgroup	Ratio: (component weight)/(curb weight)	
	Average value	Least value
Body:		
Basic structure	0.30	0.25
All trim	.16	.13
Glass	.04	.035
Engine	.145	.12
Automatic transmission	.05	.04
Suspension: [1]		
Front	.035	.03
Rear	.03	.025
Wheels	.027	.023
Tires	.028	.025
Brakes	.04	.035
Steering apparatus	.017	.013
Rear axle, driveline [1]	.038	.03
Exhaust system	.015	.012
Battery, electrical	.02	.012
Radiator, full [2]	.013	.008
Fuel tank, full	.042	.033

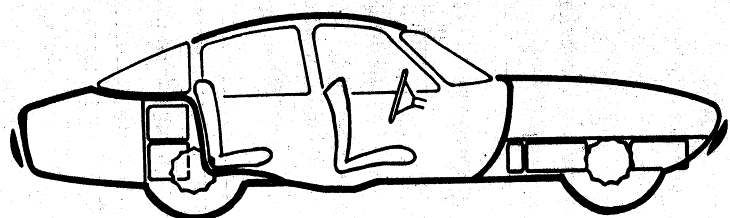
[1] Front-engine, rear-drive models only.
[2] Water-cooled engines only.

Figure 2 shows this undifferentiability either from the interior or the exterior of the car.

Eliminating those components that are not required in electric-motor propulsion would at first give the weight composition of electric cars shown in the left-hand column of table 2. It is assumed that the least-value ratios from table 1 represent the better engineered product in current demand. But there are advantageous side effects on each of these components in going to battery operation and electric motors. Some of the weight reductions and alterations applicable to each category are also enumerated in table 2, with an estimate of the weight fraction decrease. The right-hand column shows the finally altered component weight of electric cars as portions of curb weight.



CONVENTIONAL



ELECTRIC

FIGURE 2.—Diagrammatic comparison between a conventional and an electric automobile.

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TABLE 2.—*Weight composition of electric automobiles*

[Sum: 1.00=0.47+X+Y]

Component	Weight ratio [1]	Alterations possible from conventional counterpart	Weight reduction fraction	Final weight ratio
Body structure	0.25	Gage reductions in frame and chassis allowed by redistribution of concentrated weights. Elimination of midfloor transmission hump and driveline tunnel.	1/6	0.21
Trim	.13	Reduction of acoustical and thermal insulation. Simplification of dashboard furnishings and instruments. Elimination of air intake grillwork.	1/8	.115
Glass	.035	No alterations	0	.035
Front suspension	.03	Equal front/rear weight distribution. Low CG battery pack clustered near spring-body junction points.	1/6	.025
Rear suspension	.025	Same as above	0	.025
Wheels	.023	No change	0	.023
Tires	.025	do	0	.025
Steering	.013	Lighter steering mechanism from low CG, equal front and aft weight, 4-wheel traction.	1/10	.012
Electric motors				X
Energy storage				Y

[1] Least value from table 1.

The weight of electric motors divided by curb weight, is indicated by X, an unknown to be later determined from performance and speed requirements. The ratio (energy storage weight)/(curb weight), is denoted by Y, which simply equal 0.53−X. In sum, it appears that slightly more than half of the gross weight of electric cars should be made up of electric motors and energy storage/delivery devices.

III. MOTORS, PERFORMANCE AND SPEED

As mentioned earlier, the performance (or acceleration capability) of an acceptable electric car should match that of a comparable-weight modern automobile. The performance of passenger cars is usually measured by the time required to accelerate from standstill to 60 miles per hour. But initially, electric cars will be primarily "town-and-country" types of vehicles, and the performance that they should match is the acceleration capability of present-day cars at the lower speeds of 0–30 miles per hour. This implies a prime requirement that the electric-motor power available at, say, 15 miles per hour be the same as in gasoline-powered cars with automatic transmissions. Matching horsepowers at 15 miles per hour actually provides electric cars with better-than-conventional performance up to 15 miles per hour, comparable performance for 0–30 miles per hour, and somewhat less-than-conventional performance for 0–60 miles-per-hour acceleration.

The horsepower available at the wheels of latest model cars while accelerating through 15 miles per hour is shown in figure 3, and generally amounts to one-third to one-half of maximum published horsepower. This horsepower is calculated from the manufacturers' published data about the maximum engine torque, the automatic transmission's torque-converting ratio at stall, the differential gear ratio at the axle, and the number of tire revolutions per mile.

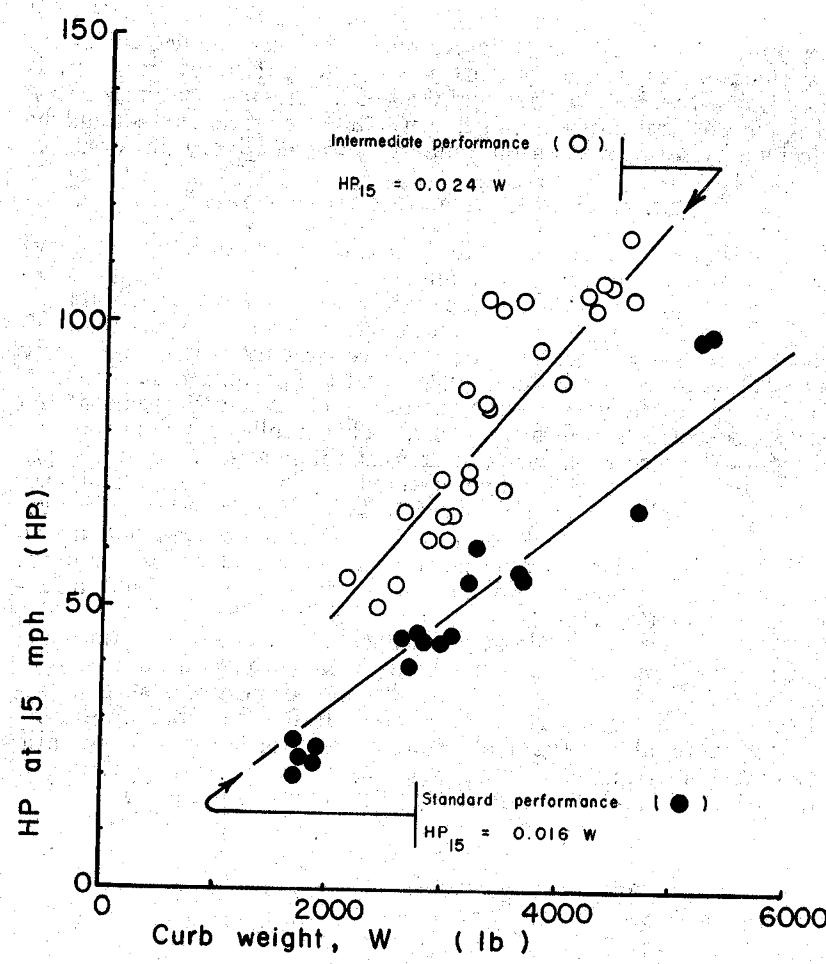

FIGURE 3.—Weight and horsepower available at 15 mph in late-model cars.

The formula for estimating the horsepower at 15 miles per hour (HP_{15}) is $HP_{15}=4.76\times10^{-5}\times$(engine maximum torque)$\times$(converter stall ratio)$\times$(axle ratio)$\times$(tire revolutions per mile) where

$$4.76\times10^{-5}=\frac{2\pi}{33,000\times4}$$

33,000=foot-pounds per minute per horsepower

4=tire revolutions per mile per tire revolutions per minute at 15 miles per hour

2π=radians per revolution.

This estimate of the available power assumes none of the various degradation factors,[2] conservatively assumed to be comparable in size to those expected in electric motors when in general use for automotive propulsion, and amounting at times to a one-quarter power loss. It

[2] George A. Hoffman, "The Automobile—Today and Tomorrow," Proceedings of the 41st Meeting of the Highway Research Board, National Academy of Sciences, January 1962, fig. 6.

may be concluded from the plots in figure 3 that electric motors should be selected so as to impart at 15 miles per hour

$$HP_{15} = (0.02 \pm 0.004) W \quad . \; . \; . \; . \qquad (1)$$

the lower figure being close to the mean of standard-performance passenger cars with curb weight W (pound), and the higher figure for medium- to high-performance U.S. cars.

The weight and power of some classes of electric motors is plotted in figure 4, based on manufacturers' specifications. Motors were assumed to be downgeared so as to turn the car's wheels at a top speed of 1,200 revolutions per minute (about 90 or 100 miles per hour). The horsepower developed was at one-sixth of this maximum revolutions per minute; namely, around 15 miles per hour. The duration and frequency of the power pulses were assumed to be patterned after suburban and light traffic driving conditions.

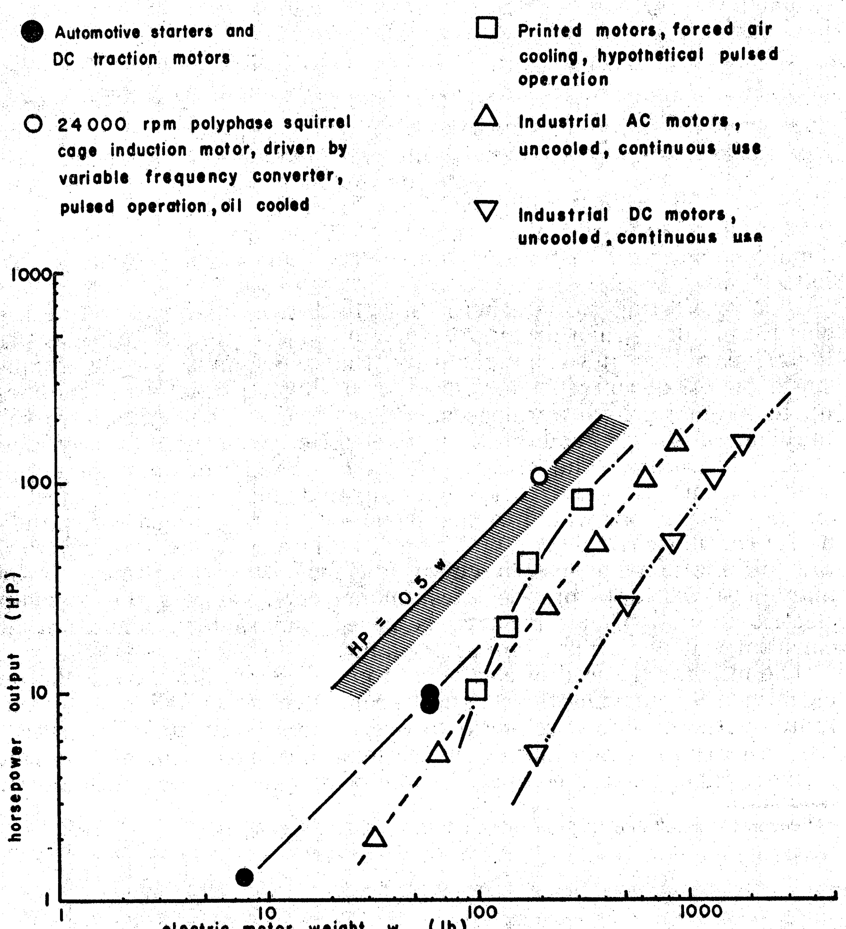

FIGURE 4.—Weight and power of electric motors.

An interesting type of motor is the polyphase squirrel cage induction motor, oil cooled and driven with a continuously variable frequency converter. This "in the wheel" motor is presently used in the integral motor wheel drive of an experimental army truck and off-road heavy vehicles.[3] These automotive electric-traction motors weigh about 2 pounds per horsepower and it is claimed that they can be designed as low as 1 pound per horsepower. Automotive motor requirements are less stringent than those usually employed for designing stationary electric motors. For example:

Full-power demands are intermittent and occur only during one-fourth to one-half of the running time.

The motor lifetime design need not be over 10^5 hours of operation.

The automotive industry has many incentives to lighten the weigh of motors by increased use of nonferrous alloys.

Forced cooling with water or oil is desirable and acceptable.

The power delivery of these future automotive-traction motors then is about

$$HP = 0.5w \quad . \; . \; . \; . \qquad (2)$$

where w (pound), is the weight of the motor and of the frequency converter. Combining expression (1) with (2), (that is, matching the initial zero- to 30-mile-per-hour performance of modern gasoline engines) gives for the electric motor weight $w=0.04W$.

With X in table 2 being w/W, and equaling 0.04, Y is equal to 0.49. In other words, about 4 percent of the weight of electric cars should be assigned to traction motors and almost half the weight to batteries.

It is interesting to note here that the torque performance of the electric motors (when driven at constant power beyond 15 miles per hour), parallels quite satisfactorily the wheel-axle, torque versus speed curves of conventional internal combustion engine automobiles up to moderate highway speeds. (See fig. 5.) This eliminates the problem of driver readaptation to electric propulsion in city and suburban traffic. The characteristics of the motor in reference 3 seem to assure that the electric car responds and performs as a piston engine-powered car would to the driver's acceleration pedal demands under the most frequent stop-and-go traffic conditions. In figure 5 the automatic transmission curve (dashed) is a composite of the manufacturers' data on the latest model cars, whereas the low-slip electric induction motor curve is based on assumed operation at constant wattage after 15 miles per hour.

The maximum speed of electric automobiles on a level road can be calculated by equating the constant propulsive power delivered by the motor with the power required to overcome aerodynamic drag, tire-rolling resistance, and any other frictional dissipative forces (the last being negligibly small compared to aerodynamic and tire resistance).

[3] "Powered Wheels," Product Engineering, vol. 37, No. 5, Feb. 28, 1966, p. 58.

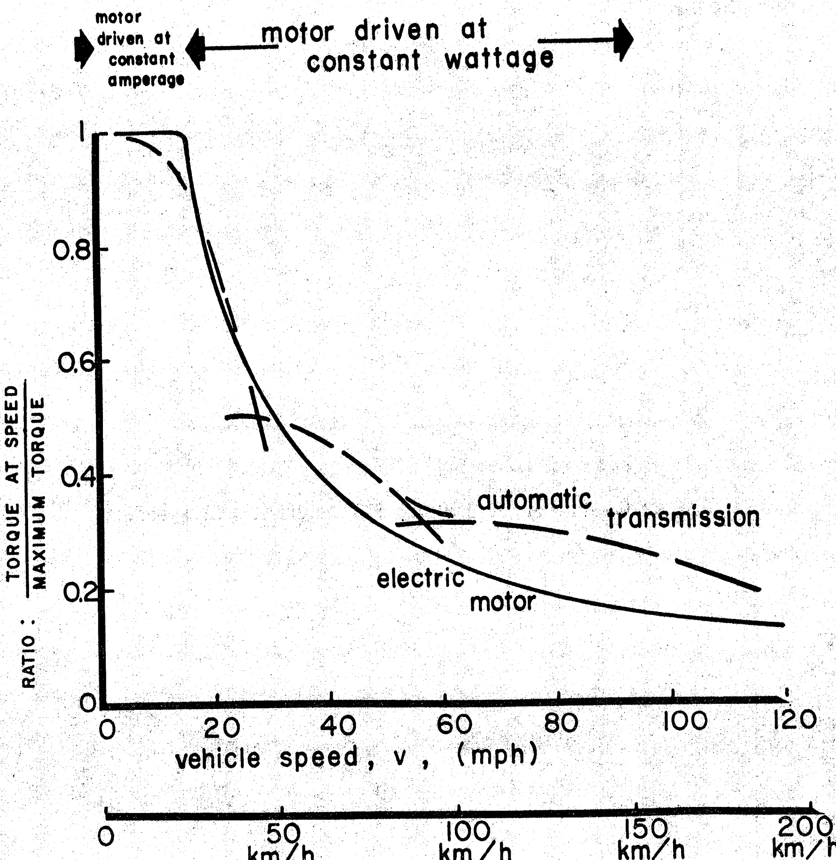

FIGURE 5.—Wheel torque versus speed characteristics of conventional automobiles and constant-power electric-motor-driven cars.

The tire-rolling drag force of passenger car tires is between 0.01 and 0.02 of the curb weight and increases with speed. For good quality, properly inflated tires (the lower bound of the band in fig. 6), the rolling tractive force [4] is about

$$(0.01+5\times10-^{5}v)\times W \; . \; . \; . \; . \qquad (3)$$

The aerodynamic drag force at 60 miles per hour of various 1960 model vehicles is shown in figure 7, indicating that this resistance for recently styled automobiles may be assumed to be

$$30+0.015(W+150) \; . \; . \; . \; . \qquad (4)$$

where 30 pounds is the drag force at 60 miles per hour of a driver's body reclining, as in the car seat, and 150 pounds is the weight of the driver.

[4] R. D. Stiehler et al., "Power Loss and Operating Temperatures of Tires," Journal of Research (of the National Bureau of Standards), vol. 64-C, No. 1, 1st quarter, 1960, fig. 8.

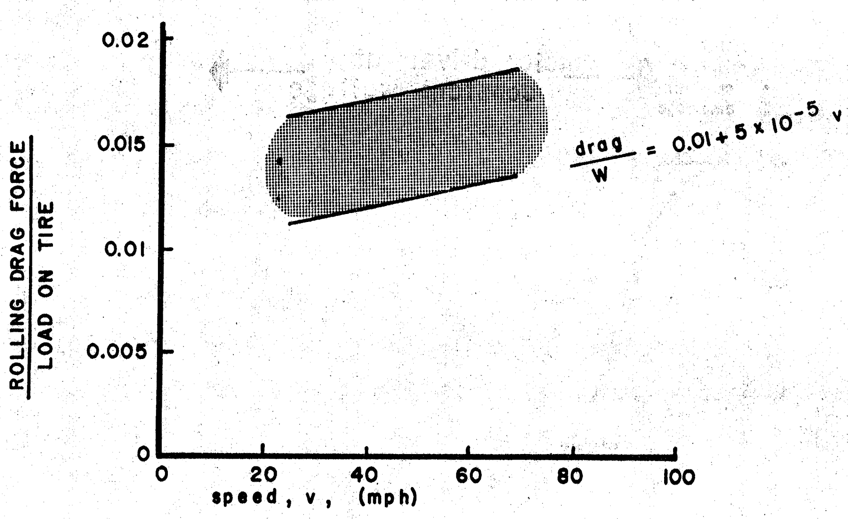

FIGURE 6.—Passenger car tire characteristics at speed.

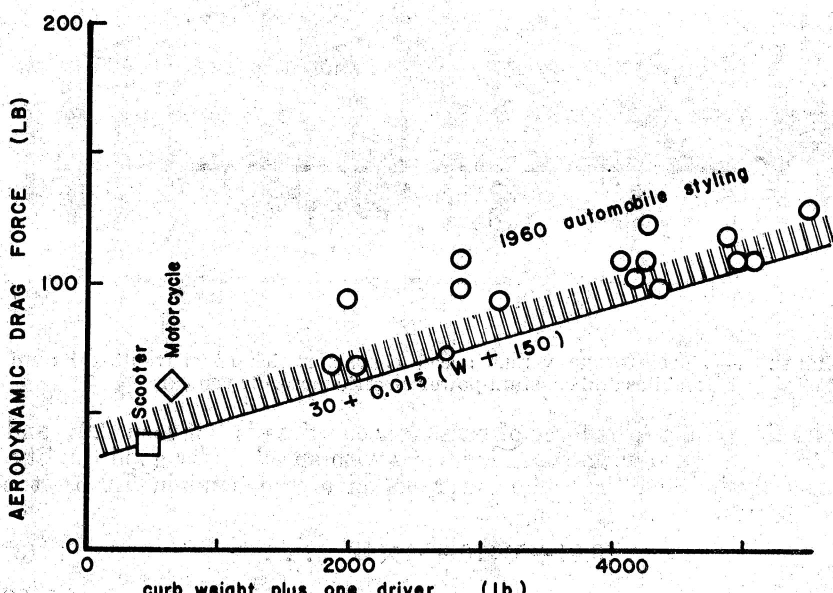

FIGURE 7.—Weight and aerodynamic drag of vehicles at 60 mph.

Aerodynamic drag of cars is quadratic with speed,[5] so that expression (4) may be multiplied by $(v/60)^2$ to yield the drag-speed relation of automobiles to be

$$[0.0083+4.2\times10^{-6}(W+150)]v^2 \quad . \; . \; . \; . \qquad (5)$$

[5] P. R. Kyropoulos et al., "Automobile Aerodynamics," Society of Automotive Engineers, reprint No. SP-180, March 1960.

The total force (pound), resisting automobile motion—that is, the sum of expressions (3) and (5)—when multiplied by the speed, v, and the appropriate dimensional conversion factors, is close to the total automotive drag power required from the electric motor. This tractive power requirement is then

$$0.00267 \times \{(0.01+5\times10^{-5}\,v)\times W+[0.0083+4.2\times10^{-6}(W+150)]\}\times v \ldots \quad (6)$$

where

$$0.00267=\frac{1.467,\ (\text{feet/second})/\text{miles per hour}}{550,\ [(\text{foot-pound})/\text{second}]/\text{HP}}$$

At the top speed of the car, V, the required horsepower in (6), (with V substituted for v) matches the motor deliverable power

$$w/2 \text{ or } 0.02\ W,\ (HP) \ldots \quad (7)$$

assuming the use of 2 pound/horsepower electric motors.

Equating expressions (6) and (7), rearranging terms, and rounding off numbers, gives the equation of the maximum speed, V (miles per hour) to be

$$V^3+\frac{V^2}{(180/W+0.084}+\frac{V}{(0.89/W+4.2\times10^{-4}}=[(0.0012/W)+5.6\times10^{-7}]^{-1} \ldots \quad (8)$$

The real solution of equation (8) is a function of W whose intricacies are beyond the scope of this paper. It is sufficient to state that the solution of (8) varies from $V=89$ miles per hour for $W=2{,}000$ pounds to $V=100$ miles per hour for $W=5{,}000$ pounds, and that $2{,}000<W<5{,}000$ is a reasonable expectation for the future mass-accepted electric cars.

It appears then that matching weight composition and initial performance of gasoline-powered cars, can result in the design of future electric automobiles capable of top speeds of about 90 to 100 miles per hour when allotting 4 percent of the curb weight to the most appropriate electric traction motors. A maximum speed of 100 miles per hour is quite respectable and useful for most driving conditions, particularly when it is available in conjunction with performance that is within 1 or 2 seconds of the competitor vehicle.

The polyphase squirrel-cage induction motor regulated for constant power by a cycle converter is observed here to be the foremost contender for automotive propulsion. It offers several automotive advantages such as being brushless and requiring no commutation, that is, it promises to be almost maintenance-free during an automobile's normal life. Furthermore, its automotive power capability is probably almost linear with its weight, eliminating many restraints on the automotive engineer's choice of number of motors per vehicle. Thus he need not contend with weight differences when considering whether to install only one electric motor (to drive the front wheels), two electric motors (one in front and one in the rear), or four electric motors (each driving a wheel). If the four-motor scheme is selected, the suspension engineer faces two alternatives: attaching each motor to the frame and driving the wheel through an axle with two universal joints, or having the motor integral within the rim of the wheel and driving it through planetary gears. This last arrangement, though the most felicitous on first observation, may result in an unavoidably harsh ride and unpleasant jounce from almost doubling the present unsprung weight by adding 1 percent of W (each motor) to each wheel-tire assembly; it would also pose unusual problems of heat dissipation into the tires from the motor.

IV. CHOICES OF BATTERIES AND RANGES

As seen in the last section, Y, the weight portion allocable for electrical energy storage and delivery, is about half of the curb weight—specifically $Y=0.49$. Two types of electrochemical energy-storage delivery systems are considered here as taking up this half of the curb weight: conventional batteries, or regenerative fuel cells with ambient air as the oxidizer source (hereafter called air-batteries for brevity).

TABLE 3.—*Properties of batteries in the near future*

(a) INDUSTRIAL BATTERIES

Type	Symbol	Energy density d, watt-hours per pound	Discharge time, hours	Method for calculating d
Lead-acid	Pb-acid	10	0.5	Manufacturers' literature on heavy-duty diesel batteries.
Nickel-cadmium	Ni-Cd	20	1	Reference 7: R. C. Shair "Sealed Secondary Cells For Space Power Systems" Journal of Spacecraft, vol. 3, No. 1, January 1966.
Silver-zinc	Ag-Zn	30	1.5	Reference 7.

(b) HYPOTHETICAL AIR-BATTERIES

Type	Symbol	Energy density d, watt-hours per pound	Discharge time, hours	Method for calculating d
Zinc-air	Zn-air	50	3	Reference 8: Hines, E., Porter, J. T. and R. J. Newman, "Zinc-Air Battery R. & D. Shows Promise" Electrical World, Aug. 23, 1965, p. 105.
Hydrogen-air	H_2-air	60	4	Scale-up of present cell-stack weights, with H_2 tank, plumbing and pumps added. Reference 9: M. G. Klein, "Electrolytically Regenerative H_2-O_2 Fuel Cell Battery" proceedings, 20th Annual Power Sources Conference, Box 891, Red Bank, N.J., 07701, May 1966.

Table 3 lists the salient characteristics of commercial and aerospace batteries, on the assumption that an intensive upgrading effort would be successful in adapting these batteries for powering automobiles in the near future. Table 3 also presents (for illustrative purposes only) the estimated properties of two hypothetical air-batteries. The first, the Zn-air battery, is hypothetical in the sense that it requires much further development and refinement before it can qualify for mass-production and automotive use, even though it is operative today and a prototype might be running a vehicle in 2 or 3 years. The last entry in table 3, the H_2-air battery, is yet to be designed, but this device might essentially be considered an electrolytically regenerative H_2–O_2 fuel cell, eliminating the O_2 tanks, and using pressurized air for the oxidizer. Its energy density was calculated by postulating a slight improvement of extant cell-stack design, and adding the least-weight of necessary H_2 tankage, plumbing, and pumps.

Hydrocarbon and several other fuel cells are omitted from table 3 because of their nonregenerative nature and their excessively low-energy densities, even though much of the research activity [6] in energy conversion is in this area. This type of fuel cells are quite feasible as electric power-generating units for cars, in the intermediate run, preceding the ultimate advent of light-weight low-cost batteries.

In all entries of table 3, the energy density, d, depends on the frequency and length of deep-discharge time. The time for discharge shown is assumed roughly to be the anticipated range divided by a representative mean speed. The distance a battery-operated car can travel before requiring either a recharge or refueling is here defined as the range of the vehicle. The range is determined by the maximum energy deliverable by the motor, which is

$$0.92YWd \quad \text{or} \quad 0.45Wd \text{ watt-hours} \ldots \quad (9)$$

where 0.92 is our assumption for the average motor efficiency in converting electrical energy to mechanical work.

The energy in (9) is expended in the work done by the engine to overcome tire and aero drag. This work is the sum of the drag forces—expressions (3) and (5)—times the range, R, when the car is traveling at a steady speed, v, on a level road on a windless spring day. This work (foot-pounds) equals

$$\{(0.01+5\times10^{-5}v)W+[0.0083+4.2\times10^{-6}(W+150)]v^2\} \times (R, \text{ miles}) \times (5{,}280 \text{ feet per mile}) \ldots \quad (10)$$

Equating energy and work; that is, expressions (9) and (10), gives the range of electric cars driven at steady speed to be

$$R, \text{ miles} = \frac{d}{0.0442+2.21\times10^{-4}v+\left(\frac{0.0395}{W}+1.86\times10^{-5}\right)^{v3}}$$

The range under this purely fictitious driving condition is shown in figure 8. The width of the band is representative of the dependence of R on W, the lower bound being for W equals 2,000 pounds and the upper for W equals 3,000 pounds.

[6] M. Barak, "Fuel Cells—Present Position and Outstanding Problems," Advanced Energy Conversion vol. 6, No. 1, January-March 1966.

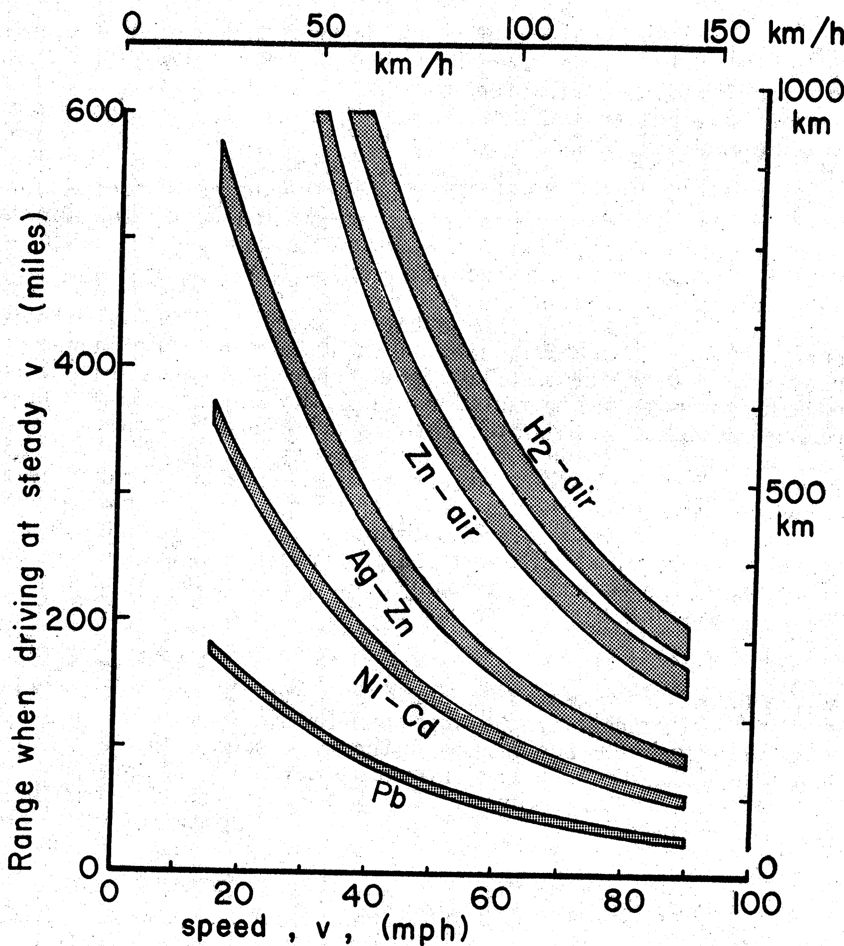

FIGURE 8.—Range of electric cars driven at steady speed.

More realistic travel simulations than steady-speed driving are needed, particularly to account for accelerations and decelerations. Two such driving conditions are assumed as shown in figure 9. Condition I represents urban travel in moderately congested traffic with considerable stop-and-go driving. Condition II defines engine utilization for suburban driving in light traffic—not on expressways.

With the mission profiles assumed in figure 9, the energy expended per trip, in steady-speed cruising, can be shown to be quite small (one twenty-fifth and less) compared to the energy required per trip for acceleration, or grade climbing. By neglecting the steady-speed energy, and stipulating that the work done in decelerating is dissipated in heat,[7] leaves only the acceleration phases to be considered.

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[7] Dynamic braking by the motor is assumed, rather than friction braking. Regenerative braking is another scheme that merits attention for energy recovery in electric automobiles. It is not incorporated in this design study because it extends the range by only one-fourth or less, but at a significant penalty in control intricacies and costs. Regenerative braking, though certainly technologically feasible at this time, is apparently not yet viable economically.

This acceleration and hill climbing is conservatively assumed to be done at close to the full-power level. (By contrast, in conditions I and II traffic, the median engine utilization by late-model cars is usually only about half of the available engine power.) The full-power assumption should compensate for the omission of the cruising power from the following calculations and account for the slightly less-than-average performance of electric automobiles at 30 to 60 miles per hour.

The energy expended between recharges is then

$$(0.02W)\times(0.35T)\times 3600\times 550/2656$$
$$\text{or } 5.22WT \text{ watt-hours} \quad . \quad . \quad . \quad . \qquad (11)$$

where

$0.02W$=maximum available motor power, neglecting road-load power
0.35=portion of conditions I and II trip time spent in acceleration
T=travel time available between recharges or refuelings (hours)
3600=seconds per hour
550=foot-pound per second per horsepower
2656=foot-pound per watt-hour

Equating (9) with (11) gives both the urban and suburban driving time between recharges to be

$$T=0.086d \text{ hours.}$$

The variability in city-driving characteristics is greatest in the block speed (total trip length divided by total trip time), achieved in a variety of settings and locations, traffic conditions and driver behavior. It is only too well known that block speeds of 20 miles per hour and even lower are still experienced at peak traffic hours in densely populated regions, while block speeds of 40 miles per hour or higher can occasionally be achieved in some suburban driving at off-peak times. The range of city-driven electric cars is therefore presented in figure 10 for a variety of block speeds, this range being simply Tx (block speed).

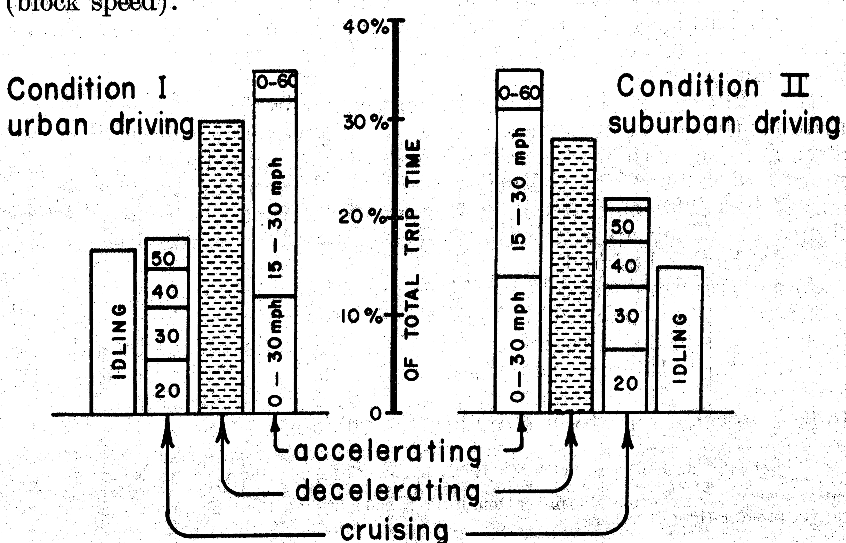

FIGURE 9.—Assumed engine utilization in city-driving situations.

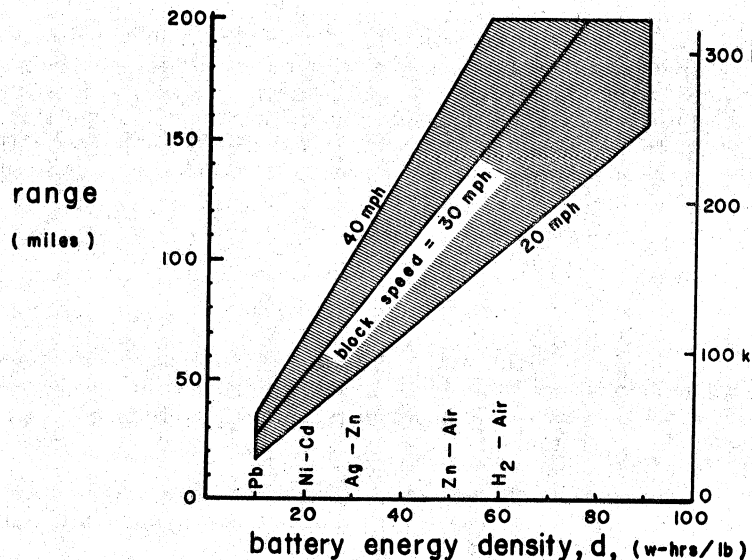

FIGURE 10.—Range of city-driven electric automobiles.

Range was only slightly affected by W in the steady-speed cruise mode, and now—under metropolitan driving conditions—the range of electric automobiles seems independent of W. One may surmise from this, that the present spectrum of car weights (from 2,000 to 5,000 pounds) and configurations (from small to large luxurious) available for consumer choice, need not change with the substitution of electric energy for combustion.[8] Figures 9 and 10 also imply that conventional batteries are unsuitable for most consumer range demands. Much better suited are the Zn-air, H_2-air and other as yet to be fully developed air batteries (for example the metal air batteries such as Fe- or Mg-air), since these yield quite respectable ranges between refueling and recharging.

It should be noted that the mission profiles in figure 9 are the most arduous that one can normally expect. Travel along routes with few stop signs or with well-coordinated lights, combined with a driver's more moderate use of the accelerator pedal than the full power assumed in (11), could result in ranges up to twice those exhibited in figure 10. They approach the ranges of gasoline-powered cars with a single thankful of fuel.

As a concluding example consider: a middle-weight automobile (say, 3,000 pounds), capable of 100 miles per hour top speed, but averaging block speeds of 30 miles per hour in the metropolis, owned by a driver insisting on a 150-mile range between refueling. This requires batteries of 50 to 60 watt-hours per pound energy density, and needs 80 to 90 kilowatt-hours to be stored in the vehicle.

[8] This conclusion contrasts with the English policy of designing very small electric cars, if any. Furthermore, the massive engineering effort in the United Kingdom toward "electricars" is erroneous in not attempting speeds higher than 40 miles per hour, or ranges greater than 40 miles.

V. SOCIOECONOMIC EFFECTS OF THE FUTURE USE OF ELECTRIC AUTOMOBILES

The societal implications of all-electric automotive propulsion in the future are investigated in this section. The first item is the forecast of a probable schedule for the introduction of electric cars into the U.S. market with an ante-facto assumption that the vehicle will prove comparable in design and costs to the nonelectric cars extent at the time.

One such schedule was worked out in figure 11. It is based on increasing mass production and mass acceptance of radically innovated cars by two orders of magnitude every 4 years, as has occasionally happened in the past with the help of American manufacturing and marketing ingenuity. Under these circumstances, it appears from figure 11 that only toward the turn of the 21st century could one expect extensive use of electric automobiles in daily travel activities.

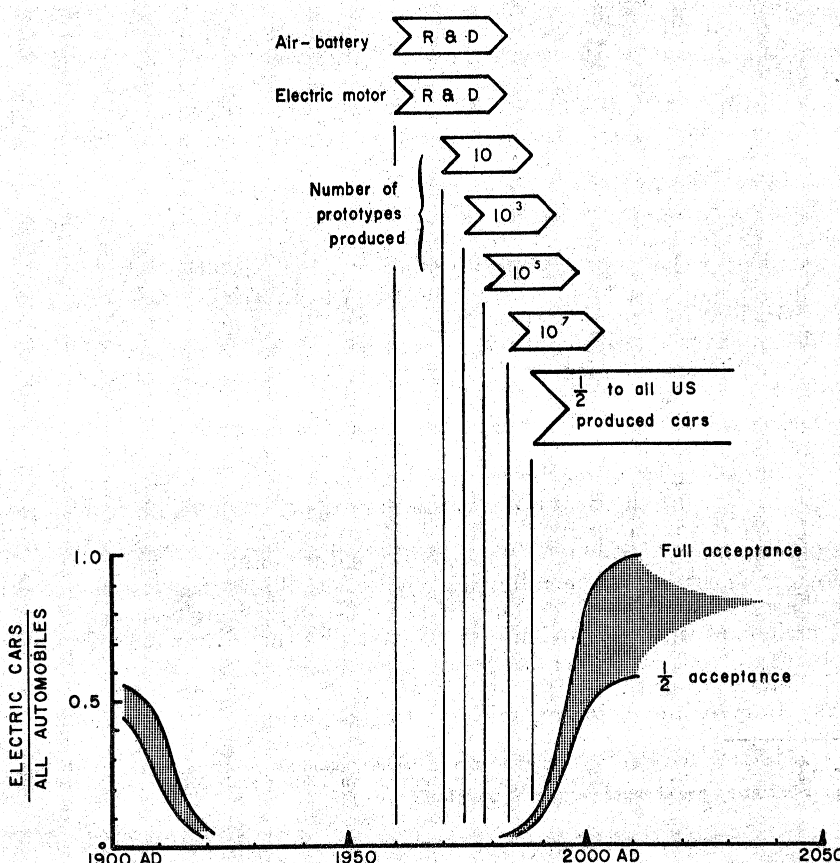

FIGURE 11.—Possible schedule for introduction of electric automobiles into the United States market.

The palpable economic effects on the consumer's pocketbook will be important. Consider first the initial (and, later, the operating) costs to the car owner in terms of the difference between electric and non-electric cars, both produced at rates of, say 10^6 to 10^7 units per year. The production unit cost—and therefore price—for half of the car weight (body, trim, suspension, wheels, tires) should be essentially the same for both types of cars. In the remaining half of the vehicle weight, a major cost jump will be encountered, due to the cost of air-batteries being intrinsically higher per pound—perhaps 1.5 times [9]—than the cost of conventional car components. Thus, as a whole, electric cars will tend to be more expensive by one-fourth than their conventional counterparts of similar size and weight.

The mass marketing of electric automobiles will require a special (but not too novel) task: to convince the prospective automobile buyers to pay considerably more at the dealer's showroom than they would pay for gasoline-engine cars; and to trade off this significant increment (one-fourth of the initial cost) against the equally significant decrement in prospective operating costs over the ensuing years of car use. The unchangeable operating costs will still be: the interest on the capital, tire replacement, road and highway taxes, maintenance, insurance, and licensing fees. But a sizable lowering in operating expenditures will be derived by switching from gasoline and oil to electric energy. A reduction of about one-half in fuel costs might be expected. Integrated over the years of the car's life, this would more than offset the initial purchase price increase.

In essence: one prediction is that electric cars will be costlier to purchase and somewhat cheaper to operate, with the operational cost savings over the years adding up to a net benefit. Automobile manufacturers will profit more from the mass production and marketing of electric vehicles that are comparable to present cars, and have the added options of highly intricate and sophisticated motors and air-batteries being substituted for piston engines and automatic transmissions.

Electric utilities will welcome the advent of electric cars: electric power consumption in the United States would about double. The price of electricity might be reduced by one-tenth or one-fifth, particularly in view of the heavy nighttime power demands as batteries are being recharged at home.

Our mounting problems of urban air pollution, mainly due to emissions from the internal combustion engine, should be greatly alleviated by battery-operated cars. One of the most significant benefits from electric cars in the future might prove to be the abatement of automotive exhaust. These emissions are costing society billions of dollars, while degrading the quality of our cities' air. We cannot afford this rapidly growing socioeconomic loss to the Nation.

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[9] Lead-acid batteries are 1½ times as expensive per pound as the average price per pound of the whole automobile. Zinc and nickel, primary candidate metals for fuel or electrodes in air-batteries, are cheaper per pound than lead.

Statement Submitted to the Subcommittee on Science, Research, and Development, by Walter A. Lyon, Pennsylvania Department of Health, August 22, 1966

Comparison of American and European Practice in Water Quality Control

Since public policy in the field of water pollution control in the United States is in the process of undergoing a number of significant changes, there seems to be value in reviewing pollution control policy in other nations. This might help us to gain a better perspective concerning activities in this country.

While there is a dearth of statistical information concerning pollution and pollution control progress in other nations, general reports from many of the European nations indicate that there has been a significant increase in stream pollution during the last half century. It is, for example, reported that in 1875, 100,000 salmon were delivered to the retail trade in the Netherlands. Between 1900 and 1915 there were only 20,000 to 30,000 per year. Toward 1930 the salmon fishery on the Rhine had lost all practical significance and its revival under present circumstances appears to be out of the question.[1] Some European pollution appears to be more recent; for example, in 1954 the Grand-Morin, a tributary of the Marne, which drains part of the Paris basin, was reported to have been a trout stream. "Today the rived is dead and covered with filthy rainbow-colored greases and hydrocarbons. Less than 10 years were needed for this." [2]

THE PUBLIC RESPONSE TO POLLUTION PROBLEMS

The public response to such pollution problems and to fish kills seems to follow a similar pattern throughout the world. Here is a report from Poland:

> Recently in an artificial lake in Poland, where the waste matter—containing a fungus that deoxydized the water—discharged by a sugar refinery caused the death of some 20 tons of fry. The press called the lake the graveyard of millions of fish. There was one good point: the public indignation at the news which gave the event greater significance than the actual economic loss, and provided conclusive evidence that the whole community was awake to the problem. Legal action has been taken against the culprits.[3]

The Polish-Anglers Union now has over 200,000 members and is a leading opponent of water-polluting industries.

As is the case in the United States, many voluntary organizations concerned with water conservation are being formed in Europe. During the last 15 years, voluntary water protection associations were

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[1] J. J. Hopmans, "The Importance of the River Rhine for the Water Economy of the Netherlands," Rhine-Seminar, United Nations Economic Commission for Europe, Geneva, 1963, p. 161.

[2] Report of Senator M. Maurice Lalloy, to the French Senate, No. 155, Paris, 1964, p. 28.

[3] Joseph Litwin, "Control of River Pollution by Industry," International Association of Legal Science, International Institute of Administrative Sciences, 25 Rue Charifé, Brussels, Belgium, p. 12.

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formed in Belgium, France, West Germany, Switzerland, Yugoslavia, and other European countries. They combined in 1956 to establish the European Federation for the Protection of Water. In Germany there exists a nonpartisan association of Federal and State legislators who are concerned with the problems of water conservation, particularly pollution. In France, a Federation of Fishermen's Associations and Amateur Anglers Defense Union played an important part in the passage of the new French water pollution control law.[4] While there have always been professional associations in Europe concerned with the problems of water pollution control, new organizations continue to be formed, such as the Swedish Association for Water Hygiene, an organization representing bacteriologists, jurists, chemists, physicians, and other technicians concerned with water pollution. A Yugoslav Association for Water Protection was formed in 1963. Its membership includes distinguished experts in the field of water economy, hydrologists, biologists, economists, and lawyers. One of its purposes is to keep the public aware of the need and advantage of pollution control.

It is, therefore, abundantly clear that in Europe, as in the United States, sportsmen, conservationists and professionals are bringing pressure upon parliaments and legislatures to pass stronger water pollution control laws.

The Swiss people, by referendum, in 1953, voted by an 80-percent majority that water protection ought to be the concern of the central government.[5]

LEGISLATIVE ACTIVITY IN EUROPE

Some countries have already passed stronger water pollution control laws and others are giving serious thought to such legislation. The Netherlands does not have a strong comprehensive water pollution control law at this time. Laws passed during the past 70 years do give the national government pollution control powers in the major rivers and ship canals.

A comprehensive water code was passed in Poland which not only controls discharges, but also indirect pollution by air and soil contamination.

During the early 1950's after some considerable study, the Belgium Parliament passed a comprehensive water pollution control law. This law is already considered inadequate and serious consideration is being given to new and stronger legislation in this field.

In West Germany, the Federal Water Act of 1960 provides, for the first time, a uniform basis for water pollution control throughout West Germany. The act provides for a permit system and imposes implementation of the act upon the West German States of Laender. Three of the West German States have refused to implement the new law and in October 1962, won a Federal court case which declared many of the provisions of the new act null and void and unconstitutional because it infringed upon the lawmaking rights of the West German States.[6] [7]

[4] Litwin, op. cit., p. 70.
[5] Litwin, op. cit., p. 69.
[6] Litwin, op. cit., p. 29.
[7] C. J. Jackson, "Trade Effluent Disposal and Water Supplies in Western Germany," Federation of British Industries, 1962, p. 9.

A comprehensive water pollution control act was passed in France in 1964. It includes all French waters including underground and coastal waters. It is not limited to discharges but covers "any activity likely to cause or increase pollution by altering the physical, chemical, biological, or bacteriological characteristics of the water." [8] The French act is very broad and leaves the details of implementation to the executive branch of the Federal Government.

In the United Kingdom, legislation passed during the last 10 years has greatly strengthened the power of the Ministry of Housing and Local Government and the river boards in the field of pollution control. The Tidal Waters Act of 1960 extended control of water pollution to tidal rivers and estuaries. The 1951 Rivers' Prevention of Pollution Act has exempted from control all pre-1951 discharges which had not materially changed in quantity or quality. The Public Health Act of 1961 requires applications for consent for the continuation of pre-1951 discharges. The 1961 act and the Water Resources Act of 1963 greatly strengthen the role of the river boards and changes the name to "river authorities." [9, 10]

Yugoslavia has no comprehensive Federal water pollution law now. Pre-1940 legislation in the various Yugoslav republics still apply except in Slovenia and Macedonia. Comprehensive Federal legislation establishing water quality standards and classifications are now being drafted.[11]

INTERGOVERNMENTAL RELATIONSHIPS

Federal legislation in the United States has, during the recent years, caused a significant shift in Federal-State relations, particularly in the field of enforcement. It is interesting to review briefly this area of intergovernmental relations in European water pollution law.

As mentioned above, in Yugoslavia the prewar water laws of the Republic prevail at this time. Only two of these Republics, Slovenia and Macedonia, have recently passed water pollution regulations enforceable within their own territories. They explicitly provide for the treatment of wastes. The other Republics, if they had any pre-Second World War water pollution control laws or regulations at all, these were very general or nonexistent. Each of the Republics has its own regulations for the protection of fisheries and these may require the installation of treatment facilities. In the field of industrial wastes, there is a Federal law which requires that no industrial enterprise may be set up or altered in any way without authorization of its investment program by the Federal Government. This includes consideration of industrial wastes pollution problems and they are, in that context, considered by the Federal Government.[12]

As mentioned above, Germany, in 1960, adopted a comprehensive Federal water pollution law which has now been, in principle, declared unconstitutional as it was attacked in court by three of the German States. Prior to that time and presumably still in force are the statutes of each of the former German States which existed before the

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[8] Litwin, op. cit., pp. 25, 96.
[9] Garner, J. F., in Litwin, op. cit., p. 149.
[10] Lyon, W. A., and Maneval, David, "The Control of Pollution From the Coal Industry and Water Quality Management in Five European Countries," Pennsylvania Department of Health, Division of Sanitary Engineering, Publication No. 13, 1966, p. 1.
[11] Stjepanovic, Nikola in Litwin, op. cit., p. 170.
[12] Stjepanovic, op. cit., p. 180.

Second World War and these are quite varied and complicated by the fact that some of the former German States have been combined and reapportioned to form other states. Generally speaking, Prussian law is typical in Germany, and it generally prohibits pollution and imposes the riparian concept of water law.[13] [14]

English law gives nearly all of the specific powers for the management of water and control of pollution to the river authorities. The Minister of Housing and Local Government merely hears appeals, which is rare. He also is responsible for formulating a national policy relating to water.

In Holland, Federal authority is limited to major rivers of national interest as is the case in the United States. Power over lesser rivers is in the hands of local watershed authorities established by the provinces.[15]

THE USE OF CLASSIFICATION SYSTEMS

The principle of stream classification crops up occasionally in European legislation. The Belgian Parliament seems to have been the first to consider this principle as is the case in some States in the United States, in the 1965 Water Quality Act, which requires the States to submit water quality criteria which, of course, is a form of classification. Poland is drafting regulations providing for classification of its streams and this appears also to be the case in the U.S.S.R. and in Bulgaria.[16] In Yugoslavia too, legislation is being drafted to include classification of water.

In France, the question of classification was debated considerably when the 1964 bill was considered by the Parliament. The French Government proposed classification but the French Senate, after the first reading of the bill, rejected the classification proposal and prescribed instead an inventory of all surface waters which would specify the degree of pollution of all the streams. The French Assembly amended the bill stipulating that water quality criteria were to be established for each stream within a fixed period of time.

THE ORGANIZATION OF WATER POLLUTION CONTROL EFFORTS

When one considers the organizational framework which exists in the field of water pollution control among most of the European nations, one finds an interesting trend to the management of most water pollution problems on a drainage basin basis rather than on a state or federal basis. In Holland, for example, although the major rivers are now and will continue to be under the supervision of the Federal Government, particularly the Ministry of Transport and Water in the National Institute for Purification of Waste Water and the Ministry of Social Affairs and Public Health, all of the other rivers are administered by watershed authorities which are formed by the provinces, and had their origin in the need of farmers to jointly share their efforts in the construction of dikes to provide protection against the sea. It is very likely that the new laws in Holland will strengthen

[13] C. J. Jackson, "Trade Effluent Disposal and Water Supplies in Western Germany," Federation of British Industries, 1957, p. 16.
[14] Litwin, op. cit., 29.
[15] Lyon and Maneval, op. cit., p. 10.
[16] Litvinov, N., "Water Pollution in Europe and in Other Eastern European Countries," Bulletin of the World Health Organization; vol. 26, No. 4; 1962.

the role of these watershed authorities which now manage most of the pollution problems of the watershed by collecting a revenue and treating the wastes of the communities and some industries.[17]

The French act is very broad in scope and leaves its implementation to the Conseil d'Etat (Council of State) through state agencies with water pollution control responsibilities, such as the Higher Council of Public Health, the Directorate of Water and Forestry, the Highways Administration, the Rural Engineering Administration, the Department of Housing, the Higher Council of Fisheries, the Ministery of Commerce and other national and local agencies. The act, for purposes of planning and implementation, sets up specific river basin authorities representing water users, local government, and other units of government. It also provides for financing, the right to levy revenues and even the power to collect effluent taxes from the polluters to compensate for the harm they caused to the general economy. The act authorizes financially autonomous river basin authorities which can implement water management on a comprehensive basis.[18]

It is probably in the United Kingdom where one finds the most sophisticated decentralized system of water quality management. While the Minister of Housing and Local Government has responsibilities in the formulation of national policy and hearing of appeals, broad comprehensive pollution control authority rests with 27 river authorities covering the entire Nation. They are responsible for not only the management of water pollution control matters, but matters relating to the entire water resource program. Each authority is, by law, an independent corporation and is not subject to detailed supervision by any central government agency although in many of its administrative duties, it may have to obtain central government consent and its decisions regarding applications for permits to discharge effluents into a stream are subject to appeal to the Minister. The river authority is governed by between 21 and 31 members which do not receive any remuneration except for expenses. The authority has a staff and is financed by contributions from the counties and boroughs which it serves.[19]

The organization of the water pollution control program in Poland provides a contrast to the United Kingdom insofar as its program is a highly centralized one. The agency responsible for water pollution control under the new 1961 law is the Central Water Economy Office, an office established outside of the purview of any of the existing ministries or departments. It is directly under the supervision of the Chairman of the Council of Ministers and has responsibility for coordinating all problems of water resources development in the Polish Government. The Water Economy Office is represented at lower levels of government but these are merely units of the central office. The office is responsible for the coordination of all state offices which have any responsibilities in the water field.[20] The 1961 act provides for the development of regional plans for the protection of water.

In Yugoslavia, the responsibility for water pollution rests with the central government for the more important streams and with the local units of government for the less important ones. This, as in Holland,

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17 Lyon and Maneval, op. cit., p. 9.
18 Dondoux, P., in Litwin, op. cit., pp. 96–97.
19 Garner, J. F., op. cit., 150–151.
20 Litwin, op. cit., p. 117.

is similiar to the situation which has now developed through recent legislation in the United States where the Federal Government takes an immediate interest in and concern with interstate streams.

In Belgium, the Ministry of Health is responsible for the control of pollution. Informal and voluntary watershed councils have been established and it is proposed that their powers and functions be considerably strengthened in a law now being considered by the Belgian Parliament.

In Germany, very general pollution control authority rests with the water and navigation offices, the water economy offices and the public health and fisheries ministries of the various German states. By all means the most comprehensive drainage basin organizations in the field of water pollution control exist in Germany. These are the German Genossenschaften. These public cooperatives or corporations are responsible under state supervision not only for water pollution control but also for the collection and treatment of wastes, flood control, drainage, the distribution and sale of water, and many related processes such as the recovery of certain industrial products from industrial wastes. Members of these river basin authorities are, broadly speaking, those who discharge pollutants into the drainage basin benefit from the facilities owned by such authorities. These usually include industrial enterprises, municipalities, and water users. The state government and the Federal Government usually are members of these authorities as well.

Each of the authorities has an assembly composed of all of its members which elects a managing board. Members are those who meet a minimum fixed contribution. The weight of a vote in the assembly meeting depends on the amount of the contribution or annual payment which is made. The laws establishing the Genossenschaften contain safeguards to prevent certain industries, particularly the mining industry from controlling the vote. Members pay contributions to the operation and maintenance of the waste collection and treatment systems which are based on an appropriate share of the annual budget. These charges are based on waste flow, waste composition, or a combination thereof. They are quite similar to the sewer service charges used in this country.

The Ruhrverband is perhaps the largest and the most complex of these organizations. It serves a watershed of 1,700 square miles. The Ruhrverband operates 100 treatment plants, 40 pumping stations, and together with the Ruhrtalsperrenverein, its water supply counterpart, operates 20 hydroelectric powerplants and 2 gas works. Two-thirds of the industries in the basin discharge their wastes to treatment plants operated by the Ruhrverband. Recreational water use is very high in the rural area. The legislation establishing the Ruhrverband makes its primary purpose the "cleaning up of the Ruhr." The actual relationship which exists between the German states and the Genossenschaften ought to be a subject of further study. It is clear that the Genossenschaften, or water authorities, must operate within the framework of German Federal and State law.[21] [22]

[21] Lyon and Maneval, op. cit., pp. 12–20.
[22] Gieseke, Paul, "River Basin Authorities on the Ruhr and on Other Rivers in Germany." Conference on Water Pollution Problems in Europe, United Nations Publication G1, II E/Mim 24; pp. 276–282.

In Sweden, the primary Federal agency concerned with water pollution control is the National Water Protection Service. Its activities are nationwide and conducted in cooperation with other agencies concerned with water pollution control such as the local health committees which concern themselves with the public health aspects of water pollution control. Applications for permits to discharge wastes to streams in Sweden and conflicts concerning water use and water pollution problems are heard and decided by water rights courts. The decisions of the water rights courts can be appealed to a superior water rights court and, if necessary and permission is granted, to the Supreme Court of Sweden. As can be seen, Sweden places a great deal of emphasis on the judicial aspects of water pollution control practice.[23]

PERMIT SYSTEMS

As is the case in most of the United States, some procedure for obtaining permits prior to discharge of wastes to streams exists in all European countries. These procedures are usually safeguarded by provisions for hearings in case of adverse proceedings. In some cases, hearings are always held prior to the issuance of a permit. In nearly all cases, interested parties are advised by public notice prior to the hearing.

It is interesting to note that the laws of many countries provide for time limits for granting permits. In England, for example, if a permit is not granted within 6 months, the permit (consent) is considered as granted free of restrictive clauses. In Poland, permits must be issued within 2 months from the date of the application. If the permit has not been issued, the officials involved must notify higher authorities requesting additional time and stating the reasons for the delay. Officials who cause the delay are subject to disciplinary action. In the United States, some State laws specify time limits for dealing with applications for permits. If no time is set and there is undue delay, applicants have, of course, the right to apply to the appropriate courts. In Yugoslavia, according to Federal Administrative Procedure Act, failure to issue a permit within 2 months means that the application has been rejected.[24]

In some countries, such as Germany, Poland, and Yugoslavia, permits for any change in industrial process are required and the question of pollution by industrial waste is considered prior to the issuance of such permits.

Most European laws, as is the case in the United States, provide for revisions or modifications or even revocation of permits. In the case of Germany and Poland, compensation can be provided for economic losses incurred by modification or revocation of permits. Similarly, many national laws provide for damages to be paid by polluters to water users. For example, in Sweden if the discharge of industrial waste water in an area has an adverse affect on fishing, the owner of the plant may be required to pay an annual amount in the form of damages to be used for "the promotion of fishing in Sweden." [25] In Poland, apart from any penalties and criminal sanctions, the water economy section can impose a special water contamina-

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[23] Dyrssen, Gösten, in Litwin, op. cit., pp. 137–145.
[24] Litwin, op. cit., p. 49.
[25] Dyrssen, Gösten, op. cit., p. 138.

tion fine, which is chargeable to the enterprises funds and can be related to the degree of pollution, particularly if there has been an arbitrary change in the manufacturing process. An enterprise to which a fine has been imposed must trace the person who caused the pollution and have recourse to law to recover the amount.[26]

The French law provides for a wide range of means to compel industrial plants to comply with pollution requirements. The Prefect, a top local government official can order the work done at the manufacturer's expense or else issue an order suspending the operation of the enterprise and, in that case, "compel the offender to pay his staff during the period of suspension." Naturally, the manufacturer has a right to appeal to the French administrative court system.[27]

SUMMARY

Any study of the dynamics of pollution control legislation and administration throughout industrialized Europe points to certain general conclusions.

First, there appears to be in Europe, a general movement toward decentralized river basin management of water pollution control and waste treatment. Second, increased pollution of streams in the industrial sectors of most countries has had an adverse effect on many of the uses of rivers, particularly recreational uses. As a result, conservationists, fishermen, and professionals have put considerable pressure on parliaments and governments with the help of an interested press. This has caused stronger laws to be considered or passed in most European countries, just as has been true for the United States. Permit and classification systems are used in Europe as well as in the United States.

In general, water pollution problems in Europe have increased as has been the case in the United States. The public response in terms of stronger laws is comparable to that in the United States. Significant differences exist in the form of organization of national pollution control efforts. In many countries the trend is toward decentralized water quality management on a drainage basin basis.

ACKNOWLEDGMENTS

Information for this paper was drawn from two major sources. The primary source has been a study conducted by Joseph Litwin, professor of administrative law, University of Lodz, Poland, for a joint committee of the International Association of Legal Science and the International Institute of Administrative Sciences, Brussels, Belgium. The study included a detailed review of reports from the Federal Republic of Germany, France, Netherlands, Poland, Sweden, the United Kingdom, the United States of America, and Yugoslavia. I have borrowed freely from the study and only cited specific quotations from the study. Much additional valuable information, particularly concerning water pollution problems in Germany, Belgium, Holland, and the United Kingdom was gathered during a travel fellowship sponsored by the World Health Organization during the fall of 1965.

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[26] Litwin, op. cit., p. 42.
[27] Gentot, Michel, in Litwin, op. cit., pp. 87–88.

Statement Submitted to the Subcommittee on Science, Research, and Development, by Phillip Sporn, American Electric Power Co., Inc., August 25, 1966

Observations on the Adequacy of Available Technology for Pollution Abatement With Particular Reference to Sulfur Dioxide

The subject of the inquiry; namely, the adequacy of our technology for pollution abatement, raises not only a highly important question for our society, but is, I think, particularly timely in view of the current deepening concern with the cumulative effect of industrial and biological wastes on our environment. While many of the situations that trouble this generation had their origins in the industrial revolution, it has remained for those oriented toward space, to apply fully the protective technologies to the indispensable bases of human life on our planet—air, soil, and water. In part, this stems from our new sense of affluence and in part from an uncritical view that fails to distinguish between the technically possible and economically obtainable.

In the hearings of last January, I pointed out that, particularly for SO_2 and other gases in stack effluents resulting from the burning of hydrocarbon fuels, the only satisfactory disposal known is the discharge at an elevated point with resultant diffusion in the upper air. I stated that the ability of a stack or stack system of practical height to lower SO_2 concentration at ground level to a value of 0.5 parts per million, even for powerplant complexes up to 5,000 megawatts, has been clearly established. I also called attention to the fact that much lower levels of SO_2 concentration have been postulated in codes and regulations, without any technical or physiological basis for such lower levels, and certainly without any demonstration that such lower levels were at all needed.

The tall stack, which is available as a perfectly solid piece of technology to take care of a pressing problem, has been neglected by some planners of facilities which could become sources of disturbing pollution. Far more distressing has been the reaction of many people concerned with creating and enforcing standards for clean air who for some strange reason have almost totally disregarded or discounted this proven technology. Instead of critically examining the incontrovertible facts with regard to the performance of high stacks, we find that various paper studies are produced and inserted in the literature in a fashion that exempts them from the criticism of other workers in the field to which scientific papers are normally subject. Later, these exempt statements are quoted overseas and elsewhere as proof that high stacks are ineffective. Along with this ostrichlike stance of officials, we have repetition ad nauseam of the bad experience of many years ago at Donora or the bad effects with washed, moistened, and chilled effluents at Bankside and Battersea coupled with massive low level emissions from household heating equipment in the much publicized tragic experience of London in 1952.

Since, in my discussion of January of this year, I did not offer any extensive proof of my statement, I would like to offer for the record the experience with high stacks in two companies with which I have been intimately associated, in one—the American Electric Power System—over the past 40 years, and in the Ohio Valley Electric Corp., of which I have been the chief executive officer since its founding in 1952.

The entire development of this technology is set forth in a paper that a colleague of mine, T. T. Frankenberg, and I prepared for submission at the International Clean Air Congress to be held in London this coming October 4–7. This will in due course be printed in full. I offer it for the record here in the highly condensed version (see p. 884).

No reading and study of this record, it seems to me, can fail to result in anything but agreement that high stacks offer a highly acceptable, effective, and so far the only available pragmatic solution to the problem of disposing of SO_2. Efforts to remove sulfur from fuel before burning it have so far come to naught. Numerous studies seeking to remove SO_2 from the flue gas have arrived at estimated costs which make the process totally unacceptable even before the operating problems have been evaluated by actual construction and operation.

In making the above categorical statement, I do not want to be charged with the belief that high stacks are a permanent solution to this problem, good for all time into the future. Very few technological solutions have any such permanency and this is no exception. But it is certainly a solution that is good for some decades to come. Still, since decades have a way of rolling around, there is need for continuing careful studies to find other solutions which can be developed to practical application. Economic application might perhaps take anything from a decade to two or three decades.

In this connection, there is certainly also need for very careful studies before and after the installation of every major powerplant utilizing the technological device of high stacks in order to obtain a more extensive evaluation of the mechanism of diffusion. Such studies will without doubt provide the students of the problem, and the designers of pragmatic technological devices for coping with them, with a degree of confidence in evaluating this mechanism and variations of this mechanism for dispersal of SO_2 so that we con continue to improve the effectiveness of the solution in the years to come without playing havoc with the country's economy.

In addition to the studies of high stacks by the Tennessee Valley Authority, alluded to in my January presentation, further attestation to the abatement possible by this means has recently come to my attention. In the July 1966 issue of the Journal of the Institute of Fuel (vol. XXXIX, No. 306, pp. 294–307), A. Martin and F. R. Barber of the Central Electricity Generating Board, Midland Region, Nottingham, England, report "Investigations of Sulfur Dioxide Pollution Around a Modern Power Station." The High Marnham Power Station, situated in a relatively flat area, has a maximum output of 1,000 megawatts and two stacks, each 450 feet high. I should like to quote briefly from the abstract of the paper:

Sixteen sulphur dioxide recorders have been sited around a modern 1,000 MW power station situated in a rural area. The recorder layout was in the form of a ring, the radius of which was the distance of calculated maximum ground-level pollution. The results from their operation during the period October, 1963, to September, 1964, are reported. On a long-term basis the overall average effect of the power station on the concentration of sulphur dioxide as measured at these sites was small (0.1 to 0.2 p.p.h.m.) compared with that already to be found in the area (3 to 5 p.p.h.m.). Most of the pollution appeared to come from distant cities and industrial areas. The most persistent effect from the power station, amounting on average to only 0.6 p.p.h.m., was to the north-east of the station and is thought to be due to the combined effects of wind frequency and strength in that direction. Short-term (3 min) power station contributions were often detectable, but under the dispersing effect of the wind, were not usually persistent at any one site. There was no significant pollution from the power station in stable atmospheric conditions, with or without fogs.

This is an example of the careful work that should be done with increasing frequency when new plants are planned and put into service. Again I would point to the record that there was no significant pollution from the plant during stable (i.e. inversion) atmospheric conditions, conditions which would however, create a great deal of difficulty for low-level emissions.

High stacks are an excellent tool when they can be designed into the plant, or even if a substantial fraction of the life of an existing plant is still ahead of it. But what can be done for plants fast approaching the end of their useful lives? Here research is badly needed and some at least is underway. This has taken the form of investigating limestone or other alkaline additives to react with the SO_2 and SO_3 present in the stack. The following groups have been active:

(*a*) Paper study of reactive rate of limestone and sulfur dioxide being done at Battelle for U.S. Public Health Service.

(*b*) Study of limestone characteristics by Bituminous Coal Research.

(*c*) In American Electric Power Service Corp., a modest research program jointly with Arthur D. Little, Inc., has just been initiated. This will cover a small section of the problem that appears particularly susceptible to direct attack at this time.

It is not expected that additives would be used full time, but as a means of operating through adverse meteorological conditions.

Possibly the most significant research program of all, since it seeks to correct our basic ignorance on the long-term, low-level effects of SO_2, is that announced since January 1966 by the Electric Research Council. In this work to be done by the Hazleton Laboratories, Inc., under contract with the council, 18-month exposures of guinea pigs and primates to SO_2 levels comparable to those found in cities and industrial areas will be conducted. Heretofore, most experimentation has been at concentrations seldom, if ever, reached even in acute air pollution disasters such as London in 1952. In order to explore the possible synergistic effects of fly ash and SO_3 mist, a number of parallel exposures will be made using these materials in conjunction with SO_2.

This statement has been somewhat longer than I first contemplated. However, the subject is one of critical importance to the power industry and is indeed an area in which it is altogether too easy to lose sight of the industry's long history of constructive activity to abate air pollution. For example, the reduction in plant heat rate from an average 22,600 British thermal units per net kilowatt-hour in 1927 to 10,493 in 1962 represents a major reduction in the potential air pollution from this source, since only 46 percent as much fuel is being used per unit of output as was the case 35 years earlier. Further, electrostatic precipitators were commonly employed to clean flue gases in the power industry a generation before the passage of the Clear Air Act of 1963.

PIONEERING EXPERIENCE WITH HIGH STACKS ON THE OVEC AND AMERICAN ELECTRIC POWER SYSTEMS

(By Philip Sporn[1] and T. T. Frankenberg[2])

1. INTRODUCTION

In October 1952, the Ohio Valley Electric Corporation (OVEC) undertook the building of two very large plants to serve a new gaseous diffusion plant of the United States Atomic Energy Commission. These plants would be located on the Ohio River, one in southeastern Ohio and the other near Madison, Indiana (1[3]). The net capacities were originally estimated to be 1,000,000 kw for the Ohio location and 1,200,000 kw at the Indiana site. At that time the ten largest thermal-electric plants in the United States had an average size of less than 600 mw. Both new plants represented difficult assignments from the standpoint of controlling air pollution. Due to the economic availability of coal of rather low quality the plants might burn fuel containing as much as 4 percent sulfur, and would discharge at least twice the amount of sulfur dioxide as any previous plant. Further, their locations in predominantly rural areas insured that any inadequacies in the disposal of the flue gases would be glaringly apparent. Therefore every effort was made to design the plants so that they would have a negligible effect on the ground level concentration of sulfur dioxide after reaching full load operation.

2. PLANNING

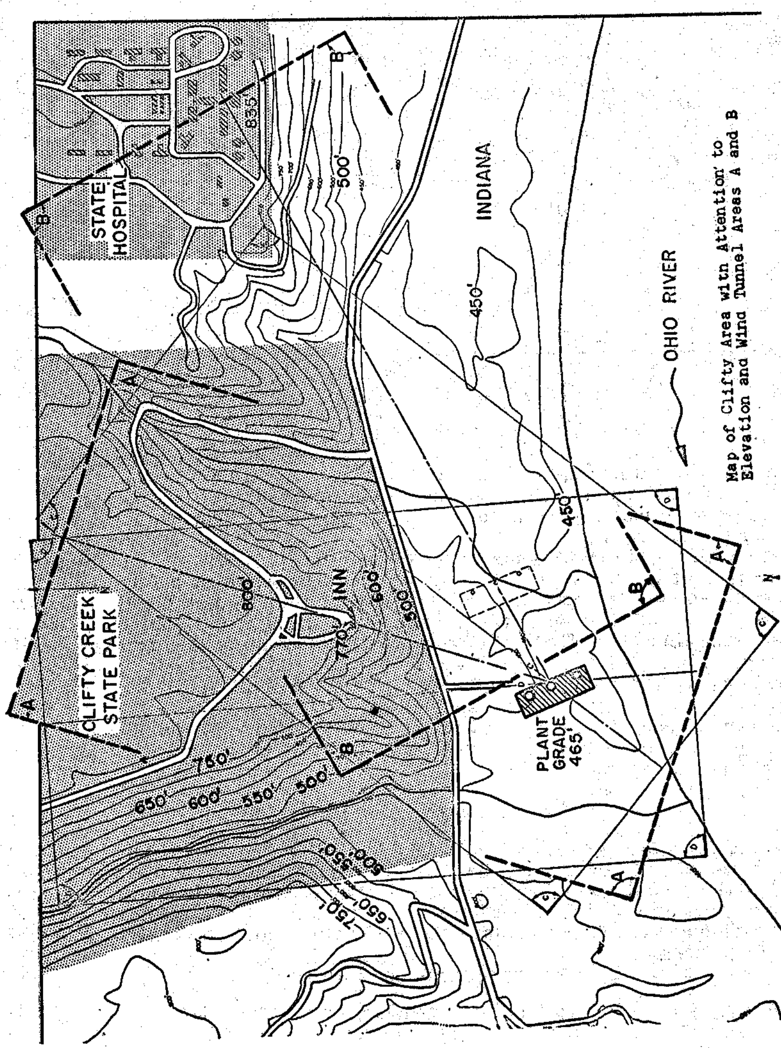
Arrangements were made to conduct wind tunnel studies of the site at Madison, Indiana, subsequently named Clifty Creek, since preliminary evaluation of this location indicated that from the aerodynamic standpoint it would present unusual difficulties. In the prevailing downwind direction from the plant, the flood plain is very short followed by an abrupt escarpment-like rise of the terrain to a plateau approximately 350 feet above the plant grade. Situated on this high plateau, at its closest approach to the plant, there is a very popular state park with an inn directly overlooking the plant site. On the same plateau, slightly further removed from the site, there is the Southeastern Indiana State Hospital for mental patients. It was deemed absolutely imperative that the highly concentrated stack plume should not descend on either of these very sensitive areas of habitation under any foreseeable circumstances. The wind tunnel work included the terrain shown in areas A and B of Figure 1, which lay in the most critical direction of the plant.

It was found that if the stack plume intersected the turbulent flow along the sharp rise to the plateau, it would immediately be brought to the ground around the inn. If the stack height was chosen so that the plume could be kept above this boundary layer, then a definite lift of the plume occurred, as shown in Figure 2. This lift varied between 50 and 150 feet and was so obvious in the wind tunnel that an allowance of 50 feet was made for the "ski jump" effect when selecting the stack heights.

3. THEORETICAL DIFFUSION CALCULATIONS

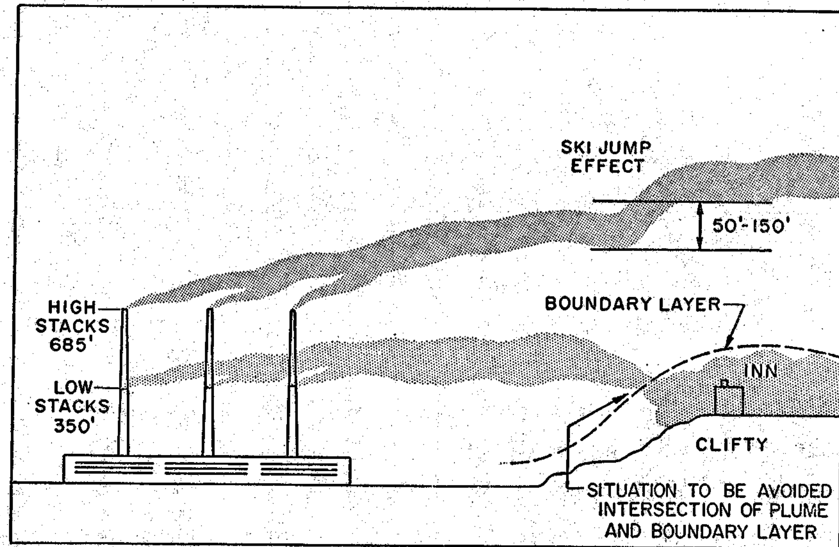
Gas diffusion calculations were carried out to determine the ground level concentrations of SO_2 at distances well beyond those that could be modeled in the wind tunnel. The Bosanquet, Carey and Halton equation (2) was used to calculate a stack gas rise and thus determine the effective stack height. With this calculated, the Sutton equation (3) was used to determine ground level concentration but with somewhat less conservative parameters (4).

[1] President, Ohio Valley Electric Corporation.
[2] Consulting Mechanical Engineer, American Electric Power Service Corporation.
[3] Numbers in parenthesis refer to references at the end of paper.



Map of Clifty Area with Attention to Elevation and Wind Tunnel Areas A and B

FIGURE 1



Boundary Layer Effect and Added Rise
Over the Hill

FIGURE 2

Irving A. Singer and Maynard E. Smith, Air Pollution and Meteorological Consultants, made almost all of the diffusion calculations for the stacks. These calculations were made using an exit gas velocity of 120 feet per second based on the wind tunnel results.

It was necessary to make some choice of the limiting value of SO_2 that would be acceptable at ground level. A value of 0.5 parts per million for a one hour period was chosen as being one fourth of the odor threshold, and low enough to keep instantaneous peak below 2–3 ppm. Only strong wind conditions would produce values in excess of 0.5 ppm SO_2 and such winds occur during a very small percentage of the total hours in the year. Thus, it can be seen that with regard to an entire year and to the whole terrain around the plant, the actual long-term factor of safety was very much greater than four.

After careful consideration of all the data and with considerable concern for possible adverse conditions during the breakup of the nocturnal inversion, a stack height of 683 feet was chosen.

4. KYGER CREEK STACKS

Having determined the stack heights for Clifty Creek on the basis of all the factors considered previously, it became an easier matter to select a proper height for those at the smaller Kyger Creek Plant. No aerodynamic considerations were present and since diffusion studies indicated that a height of 535 feet would provide acceptable conditions both in the valley and on the hills, this was the height chosen.

5. VERIFICATION OF CHOICE

Basic to the pioneering work on these two large plants was the decision to make the necessary effort to verify the design by testing for both SO_2 and dustfall prior to operation and for a substantial period after commissioning. Dustfall studies were discontinued three years after full load was reached when it became abundantly clear that the plants had had no significant effect on this variable.

Three Thomas Autometers were installed near each plant to obtain a continuous record of sulfur dioxide at or close to ground level. One was located in the valley, Station A, while Stations B and C were on the plateau. A careful review of the sulfur dioxide records made late in 1959, after approximately four years of operation of both OVEC plants, showed no hourly mean concentrations above

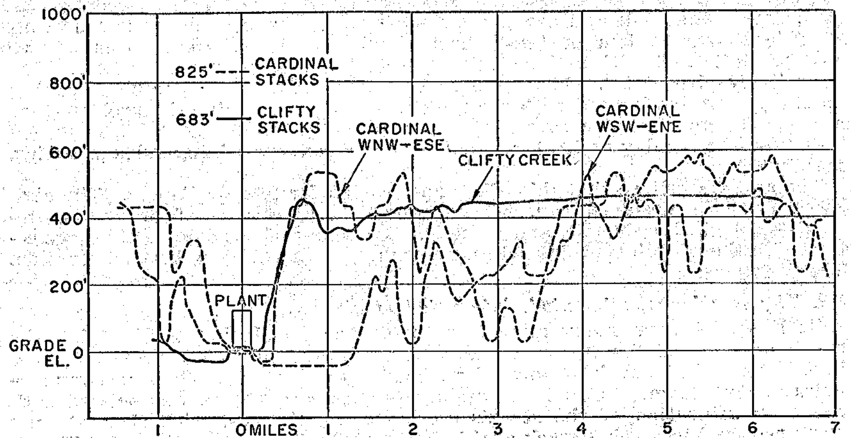
1 ppm of sulfur dioxide for either plant. It was agreed that concentrations slightly above that level may occur infrequently on the plateau north of Clifty Creek Plant, with an occasional peak value just reaching the odor threshold. In general it was found that the original calculation of concentrations at both plants had given somewhat higher values than were actually experienced.

The most gratifying finding was that the meteorological condition which was expected to give rise to a severe problem, namely the breakup of nighttime inversions, with calculated concentrations of 5 to 10 ppm, failed completely to follow the mathematical model. This model, which did not involve the Sutton equation, was based on the idea that the gas would all be confined to a narrow wedge of quite limited height below the inversion. Although there was a tendency for the recorded ground level concentrations of sulfur dioxide to occur during the mid-morning hours, there was not a single case of the very high concentrations typical of fumigations. The results seem to indicate that the more restrictive ideas concerning the maximum size of thermal plants based on purely theoretical fumigation calculations (5) should be reviewed and considerably modified toward permitting larger aggregation of power generation equipment at a given site.

It was found that recording of any sulfur dioxide was an unusual event, averaging only 1.8% of the daylight hours, with a maximum at the valley station of 3.0%. Night hours showed SO_2 present only an average of 0.3% of the time. When sulfur dioxide was present it averaged only 0.10 ppm with short-term peaks at some stations reaching 0.40 ppm. The records clearly establish the fact that these tall stacks eliminate ground level concentrations during inversions. Only a small proportion of the observed concentrations occurred at night when the inversions were normally present. When concentrations did occur at night, it was generally apparent from the winds, temperatures, or observations by the plant personnel that no inversion was present. Thus, the inversion which is so often described as a "lid" holding down noxious gases, actually becomes a shield preventing the return of stack gases if they are first emitted at a height, velocity and a temperature which are reasonable and appropriate.

6. CARDINAL STACKS

The design of the stacks for Cardinal Plant which will have a total generation on one site of approximately 2100–2300 mw represents, in many ways, the culmination of all of the information, design and operating experience obtained since the building of Clifty and Kyger Plants. The similarity of this terrain to that at Clifty is shown on Figure 3. Here again, the plant is upwind of a substantial plateau but this plateau is broken by major and minor streams in a highly irregular fashion.



COMPARISON OF CRITICAL DIRECTION AT CLIFTY CREEK WITH 2 DIRECTIONS AT CARDINAL

FIGURE 3

After considering all factors, a stack height of 825 feet above grade was selected. This was based on many considerations, among which were the following:

(*a*) It was decided that this height represented the maximum reasonable limit to which the existing technology of stack construction could be reliably extrapolated.

(*b*) The combining of the flue gases from two or more units into a single stack would be beneficial from an air pollution viewpoint and was contemplated. However, the experience with stack repairs at Clifty Creek argued against such a choice. As it is, a single unit per stack represents approximately a 50 per cent extrapolation in capacity beyond the Clifty Creek stacks.

Also since regulations covering SO_2 emissions may be instituted under the Clean Air Act of 1963, it is possible that the third unit might have to have a higher stack than was selected at this time.

(*c*) Since only two units of the total plant development were to be built at this time, it seemed certain that there would be a period of not less than five years operation of these units before decisions were required concerning the third stack. This period of operation and observation would permit an exact evaluation of the plant's effect upon the SO_2 concentrations in the surrounding countryside.

7. SUMMARY—HIGH STACKS

It has become apparent that high stacks offer the only presently available pragmatic solution to the problem of disposing of SO_2. Efforts to remove sulfur from the fuel before burning it have, so far, come to naught. Numerous studies seeking to remove SO_2 from the flue gas have arrived at estimated costs which make the process completely unacceptable even before the operating problems have been evaluated by actual construction and operation.

It is possible that high stacks can be accepted only as an interim solution to this problem. There is need for careful studies before and after the installation of every major power plant having high stacks in order to obtain a more extensive evaluation of the diffusion equations. This might be done along the lines that have been started by the Tennessee Valley Authority (6). Such studies might provide the designer with a degree of confidence in evaluating the disposal of SO_2 that he does not possess at the present time.

8. THE COMING ERA OF 2500–4000 MW PLANTS AND SO_2 PROBLEMS

8.1. The general solution

The era of 2500 mw–4000 mw steam electric plant is not a fact that needs to be anticipated—it is here. Mention has been made of Cardinal. Recently, announcement was made of a new generating station to be located on the American Electric Power System in West Virginia with an initial installation of two 800 mw units and with a third unit to be installed sometime after 1971. The most likely size of this third unit will be 1050 mw. Thus, for coal burning plants, we are confronted with the need to critically examine the problem that a plant designer will be called upon to solve—to harmlessly dispose of 1250 tons of sulfur per day or 100 tons per hour when converted into oxides of sulfur, mainly SO_2.

The authors believe that this offers no occasion for fear or dismay. The high stack properly designed can, without question, take care of every requirement—ecological, economic, and esthetic. A number of special areas in connection with the adoption of this solution warrant further, if only brief, discussion. These follow:

8.2. The multi-compartmented, integrated stack

Such stacks have many advantages from the standpoint of obtaining the maximum rise of the hot gas, the increase in the plume's ability to pierce inversions and the maintenance of reasonable exit velocity when one or more units is shut down. Offsetting these advantages, are the costs associated with the poor utilization of the stack's cross section, the cost of horizontal duct work required to reach a stack of this type and finally, the question of ability to work on and around an idle liner while the other two or three are in use. It appears likely that several years may elapse before stacks of this general type are built in the United States.

8.3. The problem of height, material construction and maintenance

In applying very high stacks, a considerable problem with the aeronautical authorities must be faced. This is somewhat mitigated by the fact that it is already recognized that perhaps in level terrain, heights beyond 800 or 900 feet do not significantly improve the ground level concentrations. However, in hilly country such as the terrain in which the plants described are located, it is conceivable that stacks as much as 1200 or 1500 feet in height may ultimately be required.

Stack design has undergone more rapid change in the past ten or twelve years than at any time since the power industry's beginning. New materials have been tried, different construction techniques utilized, and new problems have been faced.

Currently, the stack design consisting of a reinforced concrete shell with a low-alloy, corrosion resistant steel (such as Corten) liner, appears to be adequate after approximately six years' service. Obviously, it would be desirable to have double or triple this amount of experience before concluding that it has completely solved the problem.

8.4. The monitoring and building up of technological history

The fortunate development of the high stack as a solution to the sulfur-dioxide problem presented by large coal burning plants was carried out on the basis of very meager experience. But for the future it is most important that this deficiency be remedied. The authors most earnestly recommend, therefore, as new high stacks are designed and constructed, that an effort be made to obtain data on the ground level concentrations of SO_2 for extensive periods before and after operation. Needless to say, adequate meteorological information for the evaluation of these results should be obtained either from other sources or by special instrumentation at the site.

Every generation's engineers have been the heirs to the ingenious work, records and experience compiled by and transmitted to them by their professional forebears. Air pollution represents an area in which today's engineers must in turn develop such necessary data and make it available to the generations that will follow.

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Statement Submitted to the Subcommittee on Science, Research, and Development by Earl L. Wilson, Industrial Gas Cleaning Institute, Inc., August 23, 1966

As president of the Industrial Gas Cleaning Institute, I attended your committee hearing on Thursday, July 21, and again with members of our IGCI Government Relations Committee on Tuesday, August 9, 1966. We want you to know that we are very favorably impressed with the work your subcommittee is doing and the knowledge and understanding of the committee members. We are confident that better and more practical approaches to research on pollution control will result from your efforts.

Let us first acquaint you with the Industrial Gas Cleaning Institute. The IGCI is a national association of manufacturers of gas cleaning equipment. We are concerned with the collection of particulate matter and as an institute are not presently involved with the control of gaseous emission. The IGCI encompasses all four types of air pollution control devices (particulate collectors): Electrostatic precipitators, mechanical collectors, bag filters, wet scrubbers. We represent most of the major manufacturers and an estimated 80 to 85 percent of the dollar volume of industrial dust collecting equipment sold in the United States.

We are in complete agreement with many of the statements made by the witnesses appearing before your committee and in the report of the Research Management Advisory Panel, and would like to comment briefly on what we feel are some of the more pertinent statements.

Page 3 of your report states: "Policies which aid the efficient and timely deployment of private sector scientists and engineers are desirable." We wholeheartedly endorse this statement and that of Dr. Bueche when he says, "Industry has the needed skills and facilities." We believe that such skills and knowledge are available within the gas cleaning equipment industry. Many of these concerns have been working in this area for 30 or 40 years.

We agree with the statement on page 11 of the report that "What the Nation needs is not the revenue from penalty fines imposed on polluters; rather, the need is for reduction in the volume of pollutants discharged to the environment." Industry needs help and incentive, not penalties. This is particularly true of the marginal operators who could be forced out of business by the cost of control equipment. This may sound contradictory coming from people whose business it is to sell control equipment, but it is extremely important and should be carefully considered.

Dr. Beuche said, in his most commendable statement, that the "job * * * will be completed most rapidly if attacked on a competitive basis." We firmly believe in this philosophy and were extremely gratified to note the committee's awareness of, and attitude toward, the value of profit as an incentive. The outstanding example of the value of the profit motive is the problem of SO_2 which was mentioned so often throughout the hearings. As you know, there is no economical means of removing SO_2 from effluent gases. Why? Because until the past year or so there were no controls covering the emission of SO_2. As a result, there was no market. People in business do not spend any significant amount of money on research of nonmarketable products. Even today, there are controls in only three or four small areas of the country and these regulations are met by burning lower sulphur and higher cost fuels. The controls must come first, but there must also be time to permit industry to develop an economically feasible solution.

On the question of who is to do what research, the answer was clearly and succinctly stated by Dr. Bueche when he divided research into two categories:

1. Research that will produce information useful for establishing standards, determining necessary regulations, enacting appropriate laws and suggesting methods; and
2. Research that will produce information useful in developing hardware and systems that can be manufactured and sold.

No. 1 is strictly within the realm of the Government and No. 2 that of industry. Also, due to the urgency of the problem, there should be some governmental support of private research.

During Dr. Bishop's testimony, Mr. Daddario, you raised the question of how the steel industry selects a collector to do a certain job and why there isn't an industry standard for a given application. It is regretable that there wasn't ample time for Dr. Bishop to give a more complete and definitive answer because, at this point, we felt that there was a lack of rapport between the witness and the members of the committee. In areas such as this, we feel that our institute could lend the committee valuable assistance. In this letter, we cannot go into all of the details involved relative to your steel industry question; but, because two or three types of equipment will do the job required, many things must be considered in selecting the equipment to be used, such as—

1. First cost versus operating and maintenance costs.
2. Available space.
3. Availability of water.
4. Power consumption.
5. Disposal of waste product, wet or dry.

In Mr. Arthur C. Stern's testimony on July 21, there is, perhaps, an implication that industry, and in particular the air pollution control industry, is not making an adequate effort in research. We would like to clarify this situation in regard to the gas cleaning industry. Because there is little or no control of gaseous emissions to date, and our members account for 80–85 percent of the particulate collectors sold, we essentially are the air pollution control industry as it is presently constituted.

Contrary to popular belief, ours is not a large industry. The total annual domestic sales of the members of the IGCI (no auxiliary equipment or installation costs included) for the past 5 years are:

Year:	Total sales (orders)
1965	$53,069,033
1964	45,742,415
1963	31,831,689
1962	32,402,895
1961	29,152,896

Since most of the companies in this industry were operating at close to the break-even point for 10 years up until 1964, it is clear that there was little money available for research. We do not know whether or not these figures surprise you; but, if not, you are one of the knowledgeable few who are aware that the industrial air pollution control industry is not the vast, rapidly expanding industry it is so often pictured to be.

Mr. Stern also stated that, "in the area of particulate control, device development has been confounded by the lack of uniform criteria for data evaluation and equipment performance." Mr. Stern is quite correct in this statement and this is precisely why the IGCI undertook the establishment of standards immediately after its founding in 1960. For your information, we are enclosing copies of the standards we have completed to date. This, of course, is a continuing task and more such standards will be published shortly.

Again, your committee is doing an outstanding pob and we offer our services and cooperation. Since we were not asked to testify, we have taken the liberty of submitting some of our thoughts in this letter. We would be happy to meet with you and your committee if you so desire or try to answer, by letter, any questions you might have.

STATEMENT SUBMITTED TO THE SUBCOMMITTEE ON SCIENCE, RESEARCH, AND DEVELOPMENT BY CONGRESSMAN DON EDWARDS, OF CALIFORNIA, SEPTEMBER 6, 1966

Mr. Chairman, as a Representative from a State which has its own serious and well-known problems of pollution of our environment, I am very pleased to be able to present this statement to your committee as you inquire into the adequacy of our technology for controlling pollution.

The deleterious effects of pollution for plant and animal life, for human health and comfort, for our economy and our recreational life, are reaching a critical stage. An unfortunate byproduct of the growth and development of America as an urban, industrial nation has been the pouring into our waters, air, and land, the waste of our produce. As we have taken out and used the resources of the earth, we have paid little if any attention to the quality of what we put back. We have reached a point where if we do not take forceful comprehensive steps to clean up our own filth and to place effective controls on the source of pollutants, we shall indeed stifle life on earth.

We are essentially a user society, as opposed to a consumer society. While the streamflow and the amount of air remain constant, the degree of pollution is ever greater with the increased production and consumption of goods, the increased number of cars, the increased demands for heat and electric power and the urbanization and concentration of people.

The Federal Government has an undeniable and essential role in reversing this deadly trend. I strongly support the legislation now before the Congress to amend and expand last winter's Water Quality Act and Clean Air Act and I will support strengthening of these bills. We must recognize that this problem is not limited by State lines. Air currents know no State boundaries. Nor do streamflows. The Federal Government, with its vaster resources, can financially assist local governments in construction and operation of treatment plants and other facilities. And it can offer incentives to municipalities and industries to take requisite action. Nationally coordinated research can avoid duplication and wasted money. Finally, I recommend strengthening the enforcement powers of the Government of the United States. I'm in total agreement with the President's recommendations in this regard, as he outlined them in his message to the Congress in February of this year.

It is imperative that the National Government take the lead in this field both because of its financial resources and its interstate character. But there is the additional and more crucial reason that without this potential force, we will not even be able to come close to cleaning up our environment. Without the clearly defined national goals, forcefully implemented, of unspoiled rivers and pure air, industries and municipalities and individuals will continue to dump their refuse and soot into surroundings belonging to all Americans.

How many small towns across the country have allowed their prime industry to continue to pollute the rivers and the air for fear that attempts to regulate may stimulate the plant to move? How many of these towns do not have sufficient funds to construct a modern, efficient sewage treatment plant? Instead of air pollution devices—or safety features—the automobile industry has offered an unending and amazing assortment of gimmicks—from blinding chrome to stereo phonographs—to catch the eye of the buying public.

These are the reasons why Federal action is unavoidable if we desire to achieve the goal the President has outlined.

It has often been said that our technology is adequate to the problem, if only it were applied. Although this is not entirely accurate, there is much to this statement. For example, no technical advances are needed for alleviating pollution from farm animal wastes, particulate materials in the air and sewage effluents—only standards and regulations, controls and devices. Pittsburgh's battle against air pollution is justly renowned. By placing controls on soot and restricting the use of high-sulfur fuels, pollution in that city was reduced by 67 percent in 2 years.

Nonetheless, it would be foolish and shortsighted to say our technology is adequate to our needs. Development of feasible technology has been hindered by some important factors which we might consider at this point. First, it has been shown that there is not sufficient communication of the knowledge we do have—particularly between the research scientist and the engineer. More work is needed in both basic and applied research but the work of the scientist and engineer must interact in order to stimulate progress on both ends.

We cannot overlook the problems of cost and market for developing technology. Without a requirement to do so, without a clear profit incentive, industries and municipalities have not pressed for improved equipment; thus there has been no market for such hardware. Conversely if these considerations were reversed, I have little doubt that we would see a competitive development of new, effective, low-cost equipment for pollution abatement.

At this point, the most serious problem in my home State of California is air pollution. A conservative estimate is that, across the Nation, damage to crops, deterioration of buildings, bridges, and machines runs over $11 billion a year. Each year these pollutants are released into the air: 65 million tons of carbon monoxide, 23 million tons of sulfur oxides, 15 million tons of hydrocarbons, 12 million tons of other matter. These pollutants may be transformed by a chemical process, such as oxidation; or they may blow away or fall to the ground. The ventilating capacity of the local area can only handle so much and in some areas, the geographic and meteorological problems, such as inversion, cause even greater difficulty.

Much work remains ahead of us in both research and technology. We need more research into the effects of longtime exposure in order to establish meaningful standards for control. Our knowledge of the interrelationship and secondary effects of various pollutants is not sufficient.

Clearly, two of our most serious problems are the automobile and oxides of sulfur. Incomplete combustion in motor vehicles is a major problem in every metropolitan area in our Nation. The national requirement of control mechanisms is a significant beginning. I am in full accord with the more extensive recommendations of Mr. Norman Cousins, chairman of the mayor's task force on air pollution, New York City, and I'd like to reiterate these points as he presented them to the Committee on Public Works earlier this year.

First, that studies should be made to determine whether the blowby and afterburner devices required under the Clean Air Act might not have the adverse side effect of emitting oxides of nitrogen, thus creating a substantial new problem.

Second, effective air pollution control devices should be required for all cars, regardless of age.

Third, extensive research should be aimed at the idea of developing chemical additives for use in all fuels which now produce pollutants, including fuels used in automobiles, buses, trucks, heating furnaces, and steam and power generating stations.

With respect to sulfur oxide, a great deal of progress can be made by using low-sulfur fuels while continuing to work on improving furnaces and developing inexpensive devices to catch dust and sulfur fumes. In this whole field, I think it is extremely important to remember this point recently expressed by Senator Edmund S. Muskie, of Maine: "Additional study is needed, of course, but this fact is too often used as an excuse for delay."

The rivers and streams of our Nation have for so long a time served as a dumping ground for our waste products that it will require a major commitment of money and talent to overcome the harm done by enterprising but unthinking Americans. In this day and age, even, approximately one-fourth of our towns and cities are without any kind of treatment facility for raw sewage. Over $40 billion is required merely to catch up to the needs of the moment. In comparison, the $600 million to be spent by local communities and the $150 million by the Federal Government are totally inadequate. The sources of water pollution are many and include domestic sewage and other oxygen demanding wastes, infectious disease-producing agents, plant nutrients, organic chemicals including pesticides and detergents, industrial wastes, sediment and silt from land erosion, and heat from power and industrial plants.

Intensified research and development is urgent to keep ahead of the problem of waste treatment. We need advanced means of treating municipal and industrial wastes. Particularly, we might look into the development of joint treatment systems such as is that shared by the Potomac communities of Lake, Md.; Westernport, Md.; and Piedmont, W. Va.; and the West Virginia Pulp & Paper Co.

New methods of solving the problems of cities which have combined storm and sanitary sewers are sorely needed. Over one-third of our Nation faces having their sewage flow untreated into their streams because of the overflow of the system during storms.

Another area of investigation for our scientists and engineers would be to develop alternative methods of waste disposal, instead of the age-old one of unloading it into our rivers. Basic research will always be in demand to determine the effect and fate of new chemicals discovered and used in industry and on such complex problems as recently cropped up in Riverside, Calif. when *Salmonella typhimurium* was polluting that city's well water supply.

Two indispensable elements of a successful program in combating water pollution are money and enforcement power. Funds are required to support both research and construction. The demand for treatment plants alone will require $20 billion in the next 6 years. The Federal share of this should be at least $1 billion annually and should constitute a contribution of 50 percent of the cost. The present dollar limit for any one city's project should be removed for this is unrealistic and unfair to our large metropolitan areas.

Insofar as enforcement authority is concerned, I strongly support my colleague, Representative John D. Dingell, who has done a great deal of work on this, in urging that the Secretary of the the Interior be authorized to call a conference for intrastate as well as interstate streams on his initiative without the requirement of the Governor's consent.

There is much to be done. Our technology is closely related to the climate we create for its growth and to the goals the public sets for its use. Although there is no question but that the situation is urgent and requires immediate action, we can take heart from the tremendous example set by West Germany. With over one-half the West German industrial capacity located along the Ruhr River, with that river's relatively small streamflow, we may be surprised to learn that the Ruhr is not polluted. Their method was one which we might consider: industrial plants are charged a stiff fine proportionate to the amount of pollution each plant puts into the river. I feel sure that with the wholehearted support of the public and the Federal Government, we can do as well. As President Johnson has said: "We see that we can corrupt and destroy our lands, our rivers, our forests, and the atmosphere itself—all in the name of progress and necessity. Such a course leads to a barren America, bereft of its beauty, and shorn of its sustenance. We see that there is another course—more expensive today, more demanding. Down this course lies a natural America restored to her people. The promise is clear rivers, tall forests, and clean air—a sane environment for man." The responsibility and the opportunity lie before us to take this other course.

STATEMENT SUBMITTED TO THE SUBCOMMITTEE ON SCIENCE, RESEARCH, AND DEVELOPMENT, BY EVERETT P. PARTRIDGE, CALGON CORP., SEPTEMBER 12, 1966

In the flood of reports by committees and panels and of statements by organizations before congressional subcommittees few engineers with a substantial professional career in the management of water for industrial use have become involved. I now consider it unfortunate that what such engineers say to each other is not more frequently said in the public forum. The following statement may be considered a personal expiation of my sins of omission.

As a chemical engineer immersed in research, development and engineering consultation for 40 years, I offer first my convictions that:

1. We do not face an immediate national crisis with respect to water.
2. We do not lack adequate technology to meet the current actual needs with respect to control of pollution of water.
3. We cannot expect to overcome the "crisis" by simply allocating additional effort to research.

Is there an immediate national crisis? I believe not. Yes, we must work harder and harder to keep a relatively constant supply of water in condition to be reused more and more times by more and more people who desire to have more and more things manufactured by and for them. But we do have adequate time to adjust the economy of the Nation to progressively greater reuse of water.

The reasons we hear the screaming of "Crisis! Crisis!" are multiple and complexly interrelated. Perhaps the most pervasive factor is the conviction at the level of practical political management that only by crying "Wolf!" can we stimulate our society sufficiently to support even slow action.

Do we lack adequate technology to face a crisis, if one actually existed? No, of course not. Economics limits our action, not technology. Our society already has available effective technology to meet the problems posed by pollution, but it is only just beginning to face up to the cost and the readjustment of our national economy to absorb it. Few citizens comprehend that they are individual taxpayers and buyers of the products of industry must each contribute part of their personal effort in the form of earnings to buy for their use and enjoyment the clean water they are being encouraged to demand.

When we talk about new, advanced technology for control of pollution what we really are hopeful of attaining is a minimized increase in the cost of doing what must otherwise inevitably become the more and more burdensome job of keeping water reusable.

Can we create the new technology to minimize the cost of keeping water reusable? Perhaps. But we must consistently remember that we are seeking economy of operation as well as improvement in technical performance.

Appropriating any number of millions or billions of dollars in the hope of achieving a research goal does not in any way determine that the goal actually is attainable. A case in point is the saline water program, which was created specifically with the expectation that it would provide water sufficiently inexpensive to be used for irrigation in our own country. This program now seems destined to become primarily an instrument of aid to other countries so much more in need of water than the United States that they can pay a high cost for it.

A corporation invests in a number of research projects, each selected with the expectation that the benefit to the shareholders will be greater than the cost of the project. When it assumes the functions of a social corporation, the Federal Government has the same basic responsibility to invest in projects which promise to produce more real benefits than their real costs. Neither the corporation-for-profit nor the Government can expect every research project to pay off, but the adequacy of the management in each case will ultimately be judged by the ratio of those which do to those which do not.

For human beings to derive real benefits from scientific research, the results of this research must ultimately be applied by individuals who think like engineers. In the control of pollution this would mean engineering application of science in terms of large quantities of material being processed with high efficiency in equipment that will continue to function for long periods of time, producing a result at an optimum ratio of value to cost. A current criticism of engineering education is that it has been producing too few men capable of transferring the results of scientific research into processes properly engineered for efficient operation.

What are our real needs in the field of pollution control? The most immediate need is for manpower competent to apply the results of scientific investigation to beneficial uses in the—

1. Design, construction and continuing operation of treatment plants for municipal sewage and industrial wastes, employing existing technology and adapting contemporary improvements.
2. Evaluation and regulation at the level of local, State, interstate, and Federal agencies for control of pollution.

Encouraging more young men of ability with an interest in the application of technology to choose engineering training in the field of pollution control is obviously more essential to early progress in this field than the more remote research to develop new scientific information of possible utility.

The next most immediate need is to establish an atmosphere of incentive for industry to innovate improvements in processes and equipment which will compete for use in control of pollution, subject to the ultimate test of the market.

Important, but still third in order of immediacy, is Federal support of the search for new scientific facts upon which the engineer may be able to build new technology which in turn may meet the ultimately decisive test of economics.

Science is "the endless frontier." But until it is applied to the benefit of man, it yields only intellectual values to the few specialists capable of comprehending its findings. A wise government will accordingly be as concerned with encouraging the application of science as it is with the accumulation of new scientific information.

STATEMENT SUBMITTED TO THE SUBCOMMITTEE ON SCIENCE, RESEARCH, AND DEVELOPMENT BY THE ATOMIC ENERGY COMMISSION, SEPTEMBER 12, 1966

INTRODUCTION

The Atomic Energy Commission is an operating agency which also has statutory responsibility for protecting the health and safety of the public in nuclear energy activities. But beyond this legislative mandate, the Commission—and its predecessor, the Army's Manhattan Engineer District—recognized from the outset an essential responsibility for controlling potential danger to the public. Thus, from the inception of the program, special steps were taken to protect against all types of environmental pollution.

The use of nuclear energy to produce electric power is expanding at a rapid rate. Power reactors are safe and reliable, they enjoy a high degree of public acceptance, and the cost of nuclear power has dropped sharply in recent years with improved technology and with the construction of larger units.

Among the factors that affect a utility decision between fossil fuel and nuclear fuel generation are the following:

Initial capital cost

The cost of nuclear plants is generally higher than for equivalent fossil-fuel plants. However, this difference becomes less as the size of the generating unit increases. For example, recent bids received by TVA for two units of 1,100,000 kilowatts each actually indicated a slightly lower cost for the nuclear units than for a coal burning plant.

Fuel costs

In geographic areas where the delivered cost of fossil fuel is relatively high, nuclear fuel costs provide a significant advantage. Such areas include most of the eastern seaboard States, the upper Midwest, and California. Over the past few years, as the cost of nuclear fuel has steadily decreased, areas in which nuclear power appears economically attractive have expanded.

Operation and maintenance

For nuclear plants this item of cost, like capital costs, is sensitive to unit size. Under present technology and safety requirements, the staffing needs for smaller nuclear plants are considerably in excess of those for equivalent fossil-fuel plants. In the large sizes, however, a nuclear plant may require a smaller staff than a coal plant of comparable size.

Therefore, in comparative cost evaluation of fossil fuel and nuclear power, consideration must be given to such factors as unit size, relative fuel costs, the anticipated extent to which the plant will be operated (plant factor), the possibility of installing a mine-mouth coal-burning plant with long distance transmission, and any economic advantage which might be gained by adding a fossil fuel unit to an existing fossil station. In general, at the present time, nuclear power is not economically feasible in unit sizes under about 200,000 to 300,000 kilowatts or when the generating unit is operated at a reduced plant factor. In the last 2 years, more and more utilities have chosen nuclear plants over fossil plants in the larger sizes.

In our discussion of the question of pollution, we will discuss two broad areas—the potential pollution aspects of nuclear power and the technology which has been developed to control pollution.

NUCLEAR POWER AND ITS POLLUTION ASPECTS

The rate of nuclear power growth is increasing more rapidly than the most optimistic forecasters had predicted. In 1964 it was estimated that the installed nuclear capacity in the United States in 1980 would be 60,000 to 90,000 electrical megawatts. The recent large number of nuclear power announcements have raised these 1980 power estimates to 80,000 to 110,000 electrical megawatts.

With this expanding industry, one might reasonably ask if this increased nationwide use of nuclear electric power will produce serious environmental pollution problems or, conversely, if the extent of power reactor waste management operations will be of such magnitude as to deter the orderly development of the industry. The control of reactor effluents, to date, has been carried out in a safe and economical manner, and these operations have not resulted in any harmful effects on the public, its environment, or its resources. We believe this excellent environmental pollution control record will be continued.

We will summarize briefly the state of technology and of the research and development being carried out to achieve this objective.

The potential effluent control problem from nuclear power systems may be considered in two parts: (1) the handling, treatment, and disposal of increasing quantities of liquid, solid, and gaseous wastes with very low levels of radioactivity from the normal operation of civilian nuclear power stations, and (2) the processing and disposal of highly radioactive wastes from facilities which process irradiated reactor fuel to recover the unburned fissionable material.

NUCLEAR POWER REACTORS

While the management of radioactive waste at nuclear power stations is not expected to impede the development of large-scale and widespread nuclear power generation, sufficient quantities of low-activity wastes (liquids, solids, and gases) are produced to require effective and economical collection, handling and management systems, and to insure that effluent control does not become the limiting operational factor in the production of power. The scope and magnitude of these operations vary with each type of power reactor. For example, the satisfactory handling and disposal of gaseous effluents is an important design consideration for organic, gas-cooled, and direct-cycle, boiling-water reactors. The low-activity liquid wastes produced by water reactors are either treated before disposal or are reused as reactor feed water. The nature and quantity of low-activity wastes from thermal and fast breeder reactors will be evaluated as development proceeds on these reactor systems.

Waste systems for power reactors have employed conservative design criteria in terms of safety, pollution control, and plant performance. These criteria include the following salient features:

(1) Waste plant capacities are sized to handle higher than normal volumes and activities which might be caused by higher than expected corrosion and leakage rates, frequency of maintenance, and radioactivity from fuel failures.

(2) Plant flexibility is provided to accommodate waste from future fuel types, new decontamination solutions, and unforeseen abnormal wastes and cleanup solutions from accidents.

(3) Some dilution of liquid wastes by mixing with main condenser discharge water or other water is permitted in order to keep well below radiation protection standards; however, the dilution capacity of surface water streams receiving the condenser discharge water is not used to meet acceptable radiation protection standards.

(4) Limited use is made of on-site disposal for low- and intermediate-level liquid wastes or packaged, solid wastes.

(5) Piping and tanks (for all except very low-activity liquids) are provided with separate secondary containment by placing them in pipe trenches and in concrete enclosures, so that leakage can be detected and collected and returned to the waste system.

Treatment and storage systems at water reactors now operating (and those planned for the expanding industry in the next decade or more) include radioactive decay hold-up tanks, evaporators, ion exchangers, steam-stripping, catalytic recombination of hydrogen and oxygen, fixation of solids and liquids in concrete, incineration, baling, and liquid and gas filtration. In many cases, liquid wastes are stored to permit decay of short-lived radioactivity. They are then monitored to assure that they meet acceptable standards and then are released without further treatment. The waste volumes handled at power reactor facilities are not large (50 to 100,000 gallons per day for 200 to 400 milliwatt reactors) in comparison with industrial waste volumes from many other industries. The total radioactivity handled in these wastes is quite small. Radioactivity concentrations in existing power plant effluents, with no environmental dilution, have ranged from 1 to 3 percent of internationally accepted radiation protection standards for the general public. The plants have used conservative methods for establishing discharge limits.

Solid combustible wastes are generally baled (volumes reduced by 4–6:1 through the use of standard baling machines), then sealed in fiber drums or boxes and shipped off site for land burial at approved sites. Incineration of combustible wastes at power reactor sites has not been widely used because of high operating costs and the relatively small volumes of such waste handled. Disposal of ion exchange resins, evaporator concentrates, and contaminated noncombustible waste is accomplished by fixation in concrete in standard 55-gallon drums and transported by commercial firms off site for land burial. Solid waste volumes for reactor facilities of the Dresden and Yankee types amount to several thousand cubic feet per year. Final disposal of these wastes is readily achieved through commercial land burial operations at special locations on Government-owned land—currently in the States of New York, Kentucky, Nevada, and Washington—where the necessary perpetual control is assured. The capacity and availability of suitable land burial facilities do not appear to be potential problems for future power reactor operations, even with the most optimistic growth projections.

Radioactive gases are normally produced in water-cooled and moderated reactors. Some of the radioactive effluents may be associated with particulate matter. All radioactive particulates discharged to the atmosphere pass through high efficiency absolute filters which remove 99.9 percent of the particles 0.3 microns or larger. Some plants have holdup capacities for radioactive gases to permit decay of some of the species to innocuous levels. Radioactive gaseous effluents from nuclear power plants are continuously monitored at the plant and further off-site monitoring is also provided by both State and Federal agencies. Nuclear power plant records indicate gaseous discharges that are only one-tenth of 1 percent (0.1 percent) of permissible limits. In one recent case, involving a pressurized water reactor, it was determined that a tall stack for release of gaseous effluents was not necessary because of the small amounts of effluents produced.

Data for power reactor waste management systems show that capital costs for water-type reactors to date have ranged from approximately $0.5 to $4.0 million for the collection, processing, disposal, and monitoring systems required. Such costs presently constitute 3 to 5 percent of the total reactor facility cost; operating and maintenance costs have ranged between 5 and 10 percent of the overall plant operation and maintenance costs.

From an overall water pollution standpoint, a significant problem in the future may involve thermal effects from both nuclear and fossil fueled electric power plants. The magnitude and severity of thermal effects are highly dependent on local environmental conditions. That is, the availability of adequate surface water supplies for condenser cooling is becoming a major consideration in the siting of both nuclear and conventional thermal-electric generating stations. Nuclear plants of current design discharge more waste heat to the environment than a conventionally fired plant of the same size because of a lower thermal efficiency. As more efficient nuclear plants are produced, this difference in thermal effect between nuclear and fossil plants will be diminished. Auxiliary cooling systems, involving the use of reservoirs, ponds, or cooling towers, can be a solution, but installation costs of about $5 per kilowatt of plant capacity may be required over a conventional river water cooling system. However, these costs may be offset by increased flexibility in site selection, which could result in lower fuel, power transmission, and land costs.

FUEL REPROCESSING PLANTS

During the chemical reprocessing of irradiated reactor fuel to recover unburned uranium and plutonium, highly radioactive wastes are produced which must be contained and isolated from man and his natural resources for hundreds of years. The magnitude of the high activity waste management problem with an expanding nuclear power industry has been under continuing assessment as an integral part of the Commission's radioactive effluent control research and development program. For example, during hearings before the Joint Committee on Atomic Energy on the subject of industrial radioactive waste disposal held in 1959, it was estimated that using the then current processing technology the volume of high and intermediate level waste accumulated by 1980 would reach 36 million gallons.

The intervening years have brought improvements in fuels technology and in fuel reprocessing methods which have served to markedly reduce the volume of wastes generated per unit of nuclear power produced. Thus, while estimates of installed nuclear power in the year 2000 remain about the same, estimates for 1980 have risen almost fourfold from 25,000 electrical magawatts at the time of the hearings to 95,000 electrical magawatts now forecast, and predicted accumulated waste volumes in storage by 1980 have dropped by a factor of 10 to 40 (from 36 million gallons down to 1 to 4 million gallons), depending on waste handling techniques within the reprocessing plant. With the currently projected nuclear power growth rate, the cumulative waste volumes by the year 2000 are estimated at 20 to 40 million gallons, which is not inordinately large when compared with the over 65 million gallons of high activity wastes which have been satisfactorily handled in the AEC's own operations to date.

These estimated waste volumes are predicated on the assumption that confinement of the wastes will be accomplished by means of long-term tank storage of liquids. However, while more than 20 years' experience with storage of liquid high activity wastes in tanks has shown it to be a safe, practical means of interim handling, the long-term usefulness of this method is limited. This is due to the long effective life of the wastes (hundreds of years) and the comparatively short life of storage tanks, estimated at several tens of years. Accordingly, the Commission has pursued a vigorous research and development program aimed at developing and demonstrating, on an engineering scale, systems for the conversion of high level liquid wastes to stable solids and their subsequent storage in a dry geologic formation such as salt.

This solidification and disposal technology for high-activity waste appears quite feasible and practical, and has now reached the hot pilot plant and field demonstration phase. Results of these research and development programs are being provided to industry as commercial reprocessing of spent reactor fuel becomes operational during the 1966–72 period.

While it appears that the presently proposed waste management systems will fulfill the requirements for safe and economical disposal of high-level wastes from our future nuclear power industry, there are two potential problems which may require additional attention. These involve the proposed practice of releasing krypton 85 and tritium to the environment from fuel processing plants. Although these rare gases are far less hazardous than many other fission products, the release of krypton 85 at those processing plants which might be located near populous areas may impose certain operational limitations. The removal and containment of krypton 85, to prevent a significant buildup of this radionuclide in the atmosphere, may be required in an expanding nuclear power economy. Technology to accomplish this is being developed in the Commission's waste research program. Tritium, a fission product of very low yield, may also merit special consideration from the standpoint of its management in wastes from fuel processing. In the case of present solvent extraction plants, at least 75 percent of the tritium in the irradiated fuel is discharged to the environment in low-level aqueous wastes. Future plants, if situated less remotely, may be restricted in the quantity they can release to their immediate environs.

The costs of high-activity waste treatment and ultimate storage in the nuclear power future have been estimated between 0.02–0.03 mill per kilowatt-hour of nuclear electricity produced. This represents about 1–2 percent of the total fuel cycle cost and substantially less than 1 percent of the cost of nuclear power in a 4-mill-per-kilowatt-hour economy. On the basis of laboratory and engineering process data, and on an expected successful field demonstration and testing program with high-activity waste, it is believed that waste management costs will not deter the development of safe and economical nuclear power.

NUCLEAR TECHNOLOGY IN POLLUTION CONTROL

While waste management technology has been and is being developed which we believe will continue to provide satisfactory environmental pollution control systems for the expanding nuclear power industry, there are also other facets of the AEC program which are making significant contributions to the Nation's overall pollution abatement efforts. These programs deal with the development of instrumentation and monitoring equipment for the measurement and control of nonradioactive contaminants in our geohydrologic and atmospheric environments.

RADIOTRACER RESEARCH AND DEVELOPMENT

Pollution of the environment generally involves the presence of chemical substances in low concentrations. To control pollution, one must be able to measure it. Here the use of radiotracers is a particularly useful tool for quantitatively analyzing the problem, because of the extreme sensitivity of radioisotope measurements. An example of an early use of tracers was their employment in 1958 in a study of sewage flow rates near El Segundo, Calif.

In the past few years, the development and refinement of ultrasensitive analytical techniques (such as neutron activation analysis) and of sealed sources of radioisotopes have enabled scientists to apply modern methods and portable equipment for determining more accurately and conveniently the concentration of a wide variety of environmental pollutants. Activation analysis, for example, permits the use in some cases of inert tracers to follow the course of a particular contaminant without having to add radioactivity to the biosphere. Reliable and intense sources of alpha, beta, and gamma activity are incorporated in field instruments wherein the degree of attenuation, scattering, or emission of radiation is a measure of the properties of the medium.

An instrument for continuously monitoring the concentration of sulfur dioxide and ozone in air has been developed in the AEC isotopes development program for air pollution control and is under evaluation by a commercial company. This device uses a newly available radiochemical (krypton clathrate) to measure parts per million levels of sulfur dioxide and parts per billion levels of ozone. Air containing the contaminants is passed through an organic compound in which the radioisotope krypton 85 is trapped. Reaction of the contaminants with the organic material releases an equivalent amount of the radioisotope, which can be measured with great sensitivity.

For stream hydrologic work, a suspended sediment density meter has been developed, a rugged portable device for measuring the concentration of suspended sediment in rivers and streams. This unit employs a sealed source of cadmium 109 which emits soft X-rays. The degree of attenuation of the radiation is related to the concentration of sediment.

Another new analytical technique which appears promising for stream pollution studies is a portable dissolved oxygen analyzer. In this method, a radioactive material—metallic thallium 204—reacts with the dissolved oxygen, in stoichiometric quantities, in the water flowing through a column of metal particles. The radioactivity in the effluent is counted. This unit can measure parts per million concentrations of oxygen, and can provide data over longer periods of time than other devices, without interruption.

Other radiotracer work is being carried out in connection with stream pollution control for the pulp and paper industry in the State of Washington. A tracer technique using chromium 51 has also been developed to determine the efficiency of ion exchange waste treatment for chromium bearing waste solutions. Increasing use of various radionuclide tracers (krypton 85, chromium 51, and scandium 46) for sediment transport studies is another area where radioisotope technology is being used in the overall problem of environmental pollution measurement and control.

While not considered as nuclear technology, per se, the AEC in its environmental pollution research and development program has pioneered the use of a "team approach" in assessing the environmental impact of large-scale nuclear energy operations on man and his resources. The application of a wide variety of chemical and analytical techniques and competencies in many scientific disciplines, including operations and systems analyses, has resulted in comprehensive environmental evaluations of (1) stream conditions in the Clinch River below Oak Ridge, Tenn.; the Savannah River below the Savannah River plant, Aiken, S.C.; the Mohawk River below Knolls Atomic Power Laboratory, Schenectady, N.Y., and the Columbia River below the Hanford works, Richland, Wash., and (2) atmospheric conditions in the vicinity of Oak Ridge, Tenn.; National Reactor Testing Station, Idaho; and Brookhaven National Laboratory near Upton, N.Y. We believe the techniques used, including systems analysis, are equally applicable to other environmental pollution studies.

METEOROLOGICAL APPLICATION

The meteorological problems faced by air pollution abatement and nuclear energy authorities are similar, despite the differences in emphasis engendered by the differences in source materials and configurations. In many cases, such as releases from stacks, the problems are identical and the same meteorological tools may be used to estimate downwind dosages. In other cases, such as the urban area source, the meteorological parameters governing single source emission are the same but applied in a somewhat different manner.

Because of the intensity of effort and the fundamental nature of the studies of turbulence and diffusion within the nuclear energy field over the last 15 years, there has been a significant flow of basic and applied meteorological information into the air pollution technology. The various national laboratories and other contractors of the Atomic Energy Commission have carried out research in several major categories: aerosol studies, precipitation studies, atmospheric transport and diffusion studies, and the development of sampling equipment. All of these programs have direct application to the overall air pollution problem.

For example, the aerosol studies have as their objective an understanding of the interrelationships between very small particles and their environment. Since many air pollutants are aerosols, it can be seen that the work done in this category would have direct application to many of the industrial air pollution problems.

The precipitation studies are designed to understand better the effect of scavenging or the cleansing of the atmosphere by precipitation. This involves understanding the processes involved in precipitating systems and the creation, development and eventual dissipation of such systems. The scavenging of the atmosphere by precipitation is nature's method of keeping the air clean of all air pollutants. Therefore it is vital that we know more about the scavenging mechanism.

Although the programs in atmospheric transport and diffusion studies are primarily supported for the purpose of developing a capability to forecast efficiently and expeditiously the concentration of radioactive material from an accident, operational release, etc., anywhere in space and time, the results of these studies are applicable to any problem where the atmosphere acts as the transporting and diffusion mechanism. Many of the studies use nonradioactive materials as tracers. A good share of these contracts emphasize basic studies of atmospheric turbulence, since it is the turbulence which diffuses material in the atmosphere.

In other research studies, the AEC has pioneered in the use of tall towers and constant level balloons for probing the atmosphere, in the performance of some of the major diffusion experiments necessary to verify theoretical models and develop empirical techniques and in studies of the deposition and washout of material on surface features. These studies have been responsible for new techniques in meteorological instrument development and use, for plume height of rise studies and for the development of advanced climatological formats which delineate those features of local climate that determine the diffusive capacity of a site.

Another significant contribution to the quantitative assessment of air pollution problems has been the publication of "Meterology and Atomic Energy" (now being updated), a technical guide used by the nuclear industry during the past 10 years in reactor safety analyses. The calculational methods and techniques which have been developed for determining atmospheric transport and diffusion of radioactivity are now being used in the evaluation of industrial air pollution problems.

AEC STUDY OF POLLUTION PROBLEMS

It has recently been suggested that the AEC and its national laboratories be used in assisting with the problem of pollution control from fossil-fuel plants, as well as other pressing national industrial waste problem. The Commission, as part of its broad public responsibility, is vitally concerned with overall problems of pollution, and is especially interested in developing nuclear techniques or systems which would contribute to the solution of various industrial waste problems. The AEC actively promotes the maximum use by others of technology developed within the AEC complex. Further, the Commission stands ready to make AEC facilities available to other Federal agencies, where the Commission's special competence may be useful. In this connection, arrangements have been made for AEC and its national laboratory staff members to visit with the National Coal Association research group for technical discussions on the coal industry pollution problems.

SUMMARY AND CONCLUSIONS

Pollution abatement is one of the major factors being considered by the power industry in the selection of fossil fuels or nuclear reactors for electric power generation. Power reactor effluent control has been carried out in a safe and economical manner and these operations have not resulted in any harmful effects on the public, its environment, or its natural resources.

Waste management technology has been and is being developed which will continue to provide satisfactory environmental pollution control systems for the expanding nuclear power industry. Surveillance programs have been established to assure that concentrations of radioactive materials released to the environment are maintained well below internationally accepted health and safety standards. The costs of power reactor waste management to date have been nominal, and it is estimated that the future costs for treatment and storage of highly radioactive wastes which are produced in the chemical processing of irradiated reactor fuel will be substantially less than 1 percent of the cost of nuclear power in a 4 mill per kilowatt-hour economy. Instrumentation and analytical techniques using radioisotopes have been developed for use in nonnuclear environmental pollution measurement and control. Basic and applied meteorological research data from AEC programs are being used in industrial air pollution control programs.

The subject of industrial radioactive waste disposal was thoroughly and extensively discussed in hearings conducted by the Joint Committee on Atomic Energy in 1959. Among the salient conclusions reached as a result of the exhaustive JCAE hearings on this subject were (1) radioactive waste management practices have not resulted in any harmful effects on the public, its environment, or its resources; and (2) the general problem of radioactive waste need not retard the future development of the nuclear energy industry with full protection of the public health and safety. Even with the most optimistic nuclear power projections, we believe these conclusions are still valid.

The Commission is grateful for this opportunity to provide information on a subject of such vital significance to the people of the United States.

STATEMENT SUBMITTED TO THE SUBCOMMITTEE ON SCIENCE, RESEARCH, AND DEVELOPMENT, BY JAMES R. GARVEY, BITUMINOUS COAL RESEARCH, INC., SEPTEMBER 19, 1966.

My name is James R. Garvey. I am president of Bituminous Coal Research, Inc., which is the research affiliate of the National Coal Association. At our research laboratories at Monroeville, Pa., we are seeking through research to improve the means by which bituminous coal is mined, prepared, shipped, and utilized. A substantial portion of our research effort is devoted to finding means for controlling the pollution resulting from the mining and use of bituminous coal.

Our organization is supported by the bituminous coal industry, through the National Coal Association, and, in addition, receives financial contributions from the coal-hauling railroads, coal mining and utilization equipment manufacturers, and a number of the leading electric utility companies.

We believe the objective of the hearings by this committee, namely, to assess the technology for pollution abatement, to be a most laudable one. The coal industry, like many other industries, is alarmed by the rate at which legislative action commanding pollution abatement has accelerated well beyond the rate of development of feasible means for accomplishing that abatement; especially in light of the questionable need in some instances for abatement. The situation was well described by Dr. Abel Wolman of the Johns Hopkins University in his special report on pollution made to the Management Advisory Panel of this subcommittee.

> A review of the present status of water, air and land pollution and proposals for abatement thereof make reasonably clear that corrective legislation has quite well outrun both factual basis for action and smooth machinery for development and regulation.

We appreciate the opportunity to present this material, and it is our intention, in line with the objectives of the hearings, to review the state of the art of abatement, primarily, of air pollution resulting from the combustion of bituminous coal, and, to a somewhat lesser extent, the abatement of water and land reclamation involved in the mining of coal. We will attempt to brief you on the research and control methods which are currently underway and the expectations we have for the attainment of improved pollution control methods which will enable a reduction in coal's contribution to air and water pollution and land reclamation problems, and at the same time, enable the coal industry to continue as a vital part of our industrial economy.

Bituminous coal is vital since it is the primary source of heat energy used in the generation of electricity and the carrying out of many industrial processes. It is estimated that during 1966 about 263 million tons will be used for electric generation, 106 million tons will be used directly by general industries, and 94 million tons will be used in the form of coke for the manufacture of steel. This 463 million tons, combined with somewhat lesser amounts used for other purposes, including export, will bring the total bituminous coal production this year to about 534 million tons. This coal production, in addition to providing an important contribution to our industrial progress, also provides employment for more than 128,000 men and contributes $2.5 billion to the national economy.

When this bituminous coal is utilized for the generation of heat energy, whether for conversion to electricity or for direct use in industrial processing, a number of byproducts considered pollutants are produced. These include smoke, which is unburned carbon; ash, which is the noncombustible portion of the coal; and gaseous oxides of certain foreign elements in the coal, notably sulfur. The coal producers, in cooperation with those who use coal, have a long record of accomplishment in the development of means for controlling these pollutants.

The emission of smoke from a coal-burning plant is, and should continue to be, a thing of the past. Through intensive research, carried out almost 20 years ago, the technology for coal combustion without smoke pollution was developed and the modern, coal-burning plant of today emits practically no unburned carbon.

A similar situation exists with regard to the uncombustible ash of coal. The development of mechanical and electrostatic collectors has progressed to where the stack emission of "fly ash" in modern plants can be reduced to less than 0.5 percent of the original ash in the coal. Because the development of this ash control equipment is more recent than that of smoke control, not all coal-burning plants are so equipped. But as old plants are phased out of use through obsolescence, and new plants are constructed to replace them, this high-efficiency ash-collection equipment is being installed. The electric utility industry, in particular, should be commended for their efforts in the development of such equipment and the investment of non-profit-making capital to the extent of millions of dollars per plant to enable this achievement in dust control. And the ultimate in the control of dust has not yet been achieved. Research still continues and the more recent development of bag filters, which remove almost 100 percent of the dust from the gas stream, are currently being tested by a number of large utility companies.

The third byproduct which I mentioned earlier, namely, the oxides of sulfur, are the cause of the most concern at the present time. The technology for controlling this so-called pollutant is by no means as advanced as that for control of smoke and fly ash. This is perhaps understandable because it has been apparent for many years that unburned carbon in the form of soot, and unburned other constituents of coal in the form of fly ash, were true pollutants. One could see them, feel them, and readily assess the damage being done. No such means for assessment of the damage of sulfur oxides has been possible. One cannot see them or feel them, and the only way one is aware of their existence is in extreme cases wherein the concentration rises to the point where one can smell them. But this is a rare instance, and the concentrations of sulfur oxides in the air are for the most part so low that we are not aware they exist. Whether their existence is detrimental to health is a matter which has not been resolved. As was pointed out in the report of the Environmental Pollution Panel of the President's Science and Advisory Committee, "Restoring the Quality of Our Environment":

While we all fear, and many believe, that long continued exposure to low levels of pollution is having unfavorable effects on human health, it is heartening to know that careful studies have so far failed to produce evidence that this is so * * *.

Further along this line, the report of the Research Advisory Panel of this Subcommittee on Science, Research, and Development, entitled "The Adequacy of Technology for Pollution Abatement," stated:

The facts on the physiological responses of man to long-term low-level exposure to pollutants are lacking, but are necessary for setting criteria and standards. No evidence has yet been produced that low levels of pollution have unfavorable effects on human health.

However, so that I will not be misunderstood and accused of quoting out of context for a special purpose, I want to hasten to add at this point that the same report from which the foregoing quotation was taken went on to say:

But abnormal changes in animal populations are considered to be warnings of potential hazard.

We, the coal industry, acknowledge that the danger of a potential hazard exists. We believe every effort should be made to define the extent to which such a hazard exists and at the same time to develop means for needed control of the pollution which causes it. We urge that criteria and standards for pollution control be based on factual information and not on emotions. We also urge that until the exact levels of pollution which are dangerous to man have been established, the criteria and standards be set with reason in accordance with the state of the art of the technology for their control.

What is being done by industry itself in line with the determination of the tolerable degree of exposure and the development of methods for control of sulfur oxide pollutants? Our organization has been engaged in research directed at the control of this pollutant for over 10 years. In the conduct of most of this research, we have had the financial support and technical guidance of the electric-utility industry through the Edison Electric Institute and the Association of Edison Electric Cos. This research has resulted in greater knowledge of the occurrence of sulfur in coals and the development of guides for removal prior to combustion, as well as increased knowledge of the complex chemistry necessary for the development of processes for recovery of sulfur oxides from the flue gases after combustion. And, as of January 1, 1966, our program has been expanded, again in cooperation with the utility industry. A projected 5-year program has been developed at an estimated cost of $4.3 million. This research, in summary, will include:

1. A thorough study of the physiological effects of sulfur oxides, both alone and in combination with other air contaminants. This work is being carried out by the Hazleton Laboratories of Falls Church, Va. In addition, our organization, in cooperation with the oil industry and the steel industry, is sponsoring another project at Mellon Institute, also directed at determining the physiological effects of sulfur oxides. While both of these research programs will utilize animals instead of humans to study these effects, it is anticipated that the results will provide guidelines for determining the susceptibility of man to low-level exposure of pollutants.

2. Our organization, in its own laboratories, is carrying out research directed at the development of equipment which will enable the removal of additional quantities of sulfur from bituminous coals before they are burned. In many bituminous coals, the sulfur occurs primarily as a mineral pyrite which, if the coal is crushed fine enough, can theoretically be removed. However, because of the extreme fineness of crushing required (to as fine as talcum powder) in order to free these pyrite particles, the development of the necessary technology and equipment is progressing slowly. But, progressing it is, and we expect some time late this year to have installed at a central Pennsylvania powerplant the first pilot unit for achieving this reduction in sulfur content of coal.

3. We are also carrying out accelerated research on the development of low-cost methods for recovering SO_2 from flue gases following combustion. Our present research is directed at the injection of chemicals into the flue gas stream, which will react with the oxides of sulfur and deposit them with the fly ash. Again, the development of the necessary knowledge of reaction rate of various chemicals, the most effective temperatures at which the reactions should be carried out, and other design data cannot be achieved immediately. It is our intention that the basic laboratory work will be completed some time early next year, and trial installations on a full scale can be started shortly thereafter.

In addition to the research which we are doing, a number of others, including both Government and private industry, are carrying out extensive investigations. Both the Bureau of Mines and the Public Health Service are investigating processes for sulfur oxide recovery. The Bureau of Mines work will move into the early pilot stages this year, and hopefully, a full-scale installation can be made sometime the latter part of next year. The Public Health Service work, we understand, includes an evaluation and possible erection in this country of a pilot unit incorporating a process which has been developed in Germany.

Investigations by the manufacturers of equipment includes the installation of wet gas scrubbing processes. One of these has already been installed for test at a powerplant, and another is projected for installation late this year.

And, in this overall effort directed at finding a means for economical control of sulfur oxide pollutants, one of the large chemical companies, a primary supplier of sulfuric acid to industry, in cooperation with a utility company, is constructing on a substantial scale the equipment necessary for recovering the sulfur oxides from flue gases in the form of sulfuric acid which that company then will market.

In summary, the state of the art of control of pollutants from the combustion of coal is moving forward on all fronts. As I pointed out earlier, the technology for control of smoke in fly ash is already available in an advanced state, and additional progress is being made. However, much still remains to be done, despite an expanded research effort by industry, in connection with the control of sulfur oxides. Those processes which are most advanced in technical feasibility are still at the present state of development far too expensive to install and operate, especially in light of the lack of knowledge regarding the degree of control which is necessary to protect human health.

But progress is being and will continue to be made, and as the work which I described earlier, passes through the large pilot stage of development, opportunities will be available for improvements in the technology which will make them economically as well as technically feasible.

The mining and preparation of coal for shipment to market also is the cause of pollution, including air, water, and land disturbance.

Air pollution results from the spontaneous ignition and subsequent combustion of the refuse discarded in the cleaning of coal for market. Since this refuse amounts to approximately 1 ton for every 2 tons of coal produced, the amount of this material which has accumulated since coal mining began in this country is substantial. The technology for prevention of spontaneous combustion in new refuse piles has been developed, and by means of careful compaction and selection of site, this source of air pollution can be eliminated in the future. However, a great deal more work is required in the development of means for extinguishing fires and prevention of reignition in old and abandoned refuse piles. Our organization has investigated a number of approaches, including the pumping of noncombustible material into the refuse pile. Other organizations, such as the Bureau of Mines as well as other industrial groups, are carrying out additional research, and while some progress has been made the complete answer is not yet available.

Water pollution results from two sources; namely, the fine coal particles suspended in the water used for coal washing, which is in turn discarded to streams; and the acid drainage from mining areas which ultimately by natural flow finds its way into the streams. The technology for control of "black water" discharge is well advanced, and by the use of settling ponds and filters the modern coal preparation plant is rapidly making black rivers a thing of the past.

Acid drainage, however, represents a far greater problem insofar as control is concerned. The mechanism for production of acid water in a coal mine is not completely understood, and the means for changing the acid drainage from a coal mine into so-called sweet water is not as simple as many would have us believe. A large coal mine may discharge as much as 10 million gallons of water each day. The equipment and chemicals necessary for rendering this water suitable as defined by some State laws for discharge into natural streams can be extremely complex and costly. But progress is being made.

The principal object of the coal industry's attention to the solution of acid drainage problems has been in the field of eliminating those areas of drainage in operating mines. The responsible coal producers are surveying the sources of ground water which pass through their mining operations in an effort to minimize the amount which becomes acid; sampling and analyzing the waters discharged from their mines so that they can determine the degree of acidity, and the mineral content as a basis for determining the best approach for neutralization and removal of these minerals; and planning their new operations in such a manner as to reduce to the minimum the water pollution potential. Again, as in the case of air pollution control, a great deal more must be learned about the pollutant itself, both its formation and its effects, before criteria and standards for water quality can be established. Hundreds of thousands of dollars are being spent by the coal industry and associated groups in an effort to find a practical, economical, and effective method of removing the acid contaminants from the mine drainage waters. A number of theories are being reviewed. The most popular approach to the problem has been the neutralization approach. This, however, has its shortcomings in that with the volume of mine water to be treated in a large operation, the cost could be highly unrealistic.

In 1963 the Pennsylvania Coal Research Board began intensive research into various problems confronting the coal industry, with main emphasis placed on pollution control.

And just a few months ago the Northern West Virginia Coal Association announced that it would spend $150,000 for a study of that State's No. 1 water conservation problem—mine acid drainage. This 2-year study will be conducted by the West Virginia University School of Mines with two primary and immediate research objectives:

(1) To discover the sources of pollution and determine corrective measures by which its volume may be reduced; and

(2) To obtain factual engineering and economic data on chemical treatment of mine drainage by actual operation of a field pilot plant.

In the final session of this subcommittee's public hearings, Dr. Abel Wolman, a recognized authority in the field of ecology and pollution control, testified that 35 years ago he had been a member of one of the earlier research teams investigating the discharge of acid waters from mines in the Appalachian area. The project spent $20 million and in Dr. Wolman's words: "We did not succeed and the Bureau of Mines Director pointed out that they have no solution to acid mine wastes." This lends credence to the contention of the coal industry that a great deal more research and study is necessary if the problem of acid mine waste is to be solved. Dr. Wolman agreed that this was a field "where deep seated and prompt research is absolutely essential."

Much research has been done here by the U.S. Bureau of Mines and by private research organizations, as well as by those institutions supported by the various States. Perhaps there has been too much independent action by the researchers. As one means of eliminating this situation, Bituminous Coal Research, Inc., is cooperating with the Coal Industry Advisory Committee to the Ohio River Valley Water Sanitations Commission in developing a program, to be financed by funds from CIAC with BCR contributions, to set up a coordinating agency whereby all of the various research projects that are now being conducted in the area of mine drainage can be brought together and summarized and evaluated. By this means, the various independent research sponsors can recognize any areas of duplication or conflict and avoid any waste in the funds much needed for the ultimate solving of the problem. On this subject, we would urge that the subcommittee look into the possibility of a recommendation that at least a sizable part of Federal funds that are appropriated to meet the needs of research and pilot plant tests be made available to some of the independent groups that are doing such a dedicated job in this effort to find a way out of the disconcerting maze that presently surrounds every perimeter of the mine drainage continent.

Reclamation of disturbed lands is another area in which the broad concept of environmental conservation is involved. Surface mining for minerals and fuels is a mining process in which the surface of the land is removed to permit the taking of the natural resource product. This process, because of its lower cost operation and the recovery of greater quantities of minerals, provides an economical base for the marketing of the product whether it be coal or other material. In many cases, surface mining, or strip mining as it is also known, provides the only way in which large deposits of valuable materials can be obtained. In the operation of this process, there is necessarily a disturbance of the land surface. The coal industry has been often accused of being a poor neighbor for not rehabilitating this disturbed surface. For almost 50 years, however, the industry has been pursuing a voluntary program of reclamation of mined lands. Early in 1900, a request for tree seedlings was made to the Ohio Department of Forestry by a strip mine operator, but it was not until 1918 that we have any substantive evidence of this program. Then an Indiana operator planted an area in fruit trees, some of which are continuing to bear today. In 1920, in Illinois, the use of mined lands for timber production was instituted. In 1928, the Indiana strip operators organized into a group which, for the first time sponsored a program of statewide planting of lands. This effort has continued and has been so successful that today practically every responsible operator in the 22 States where surface mining is conducted is engaged in a program of land reclamation. Many of these lands are converted into recreational areas, homesites, shopping centers, and agricultural and grazing lands, in addition to the many acres which are devoted to timber protection and wildlife and bird propagation and protection. One of the major contributions which the industry's reclamation effort is making is providing water impoundments, ponds, and lakes which contribute to the source of waters for all purposes of the community.

As evidence of the industry's sincerity in the land reclamation effort, in 1962 the responsible members of the industry joined together into a voluntary organization for the purpose of encouraging, promoting, and developing the program of reclamation of mined lands. This organization—the Mined Land Conservation Conference—(an affiliate of the National Coal Association) has done much to improve the land reclamation program and provide new knowledge and practices to aid in more effective and economical methods of reclaiming mined lands. A major assist in this field is given by the MLCC Technical Committee made up of experts in all of the scientific and technical fields that are in any way connected with the adaptation of mined lands for purposes of community and economical uses. This committee serves not only the individual and group members of the MLCC but is also available without cost to all types of governmental agencies, including this committee, for such advisory or consulting services as may be helpful. In its effort to further the cause of land reclamation and utilization, the conference has instituted a voluntary industry program of surface mine conservation. The principal tenets of this code include the following:

Dispose of all refuse in a manner that will prevent stream pollution.

Prevent acid drainage both during and after the mining operation.

Where final-cut lakes are not created, cover all toxic materials in the final-cut pit.

Place pit cleaning and other highly toxic materials where they may be easily covered with clear overburden.

These practices are followed by the majority of the strip mine operators in their day-to-day operations.

In closing this statement, I would like to call the attention of the committee to what we consider to be a most important reference in the report of the Research Management Advisory Panel. This was the discussion of the need for industrial research laboratories to participate to a greater extent in the development of pollution control methods, and the role of the Federal Government in encouraging this participation. And here I quote directly from the report:

> The Federal Government routinely purchases research and development results from industry, more or less as a product. The data are used in the performance of agency missions as a basis for regulation and control administration, and for dissemination to local and state governments.
>
> In the pollution field, however, Federal research funds, for the most part, are spent intramurally or in non-profit universities and institutes. For example, it is estimated that only about one million dollars out of sixteen million dollars for fiscal year 1967 air pollution research is spent in industrial laboratories.
>
> The Federal roles in waste management technology seem to be, first, stimulus to industry to speed development, and second, the establishment of the yardstick to gage whether the state of art is ready for regulation and control measures. The direct contracting with industry for research and development on broadly applicable devices and techniques is a desirable part of the overall Federal effort in pollution.

The ultimate test of any process developed for the control of pollutants will be a full-scale installation at an operating plant, mine, etc., where the pollutant is being produced. Such installations will involve the expenditures of many millions of dollars—a large capital investment in a nonprofit operation. This will necessarily defer capital investment in other areas, which would ultimately lead to the expansion of our industrial economy. We urge that the committee give careful attention to the full report of the Research Management Advisory Panel, but also give special attention to those portions which recommend Federal Government financial assistance to industry in the development and application of pollution control methods.

(A 28-page detailed statement was received from the Advanced Products Division, VACCO Industries, South El Monte, Calif. This statement, copy of which is in the committee file, deals with the design, development, and test of a device to maximize combustion efficiency in internal combustion automotive engines.)

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