

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 electrolyze 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