cause 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,