

## ENERGY STORAGE USING HIGH-PRESSURE ELECTROLYSIS AND METHODS FOR RECONVERSION

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About 12 years ago, the School of Electrical Engineering at Oklahoma State University undertook what became a rather extensive and continuing study (both theoretical and experimental) on ways to store electrical energy and thereafter reuse the stored energy in various ways. Initially (about 1961), theoretical studies were undertaken of various possible storage methods, which included the following:

- (1) Mechanical storage (flywheels and related devices)
- (2) Pumped storage (hydroelectric)
- (3) Cryogenic magnetic fields
- (4) High-pressure electrolysis (producing hydrogen and oxygen)

From the outset, the O.S.U. group was concerned with developing energy systems which showed promise of being expandable to large-scale power systems. Thus, systems requiring exotic materials (such as platinum) were rejected from study as having little long-term possibilities on a commercial scale.

The result of our initial theoretical studies on energy storage seemed to indicate (to us at least) that high-pressure moderate temperature electrolysis had the greatest long-term economic promise, and our rather extensive experimental programs on storage were concentrated in that area. Over an 8 or 9 year experimental period, we have worked in the area of electrode design (both solid and porous), electrode and membrane life, and overall electrolysis system efficiency.

The primary results of the energy storage activity can be summarized as follows:

(1) A number of electrode designs were examined. The most successful was a solid nickel finned type of electrode (fig. 1). Electrolysis efficiencies in excess of 85 to 90 percent were achieved. Efficiency is defined as the ratio of the heat content of the gases produced to the equivalent electricity used to produce the gases. Current densities for these results ran at 400 to 700 amperes per square foot. Optimum pressures were around 200 atmospheres and optimum temperatures around 350° F (see figs. 2 and 3).

(2) Enough information was obtained so that a practical, efficient electrolysis system could be designed, built, and operated.

(3) Some studies were made of the projected cost of deep cavern high-pressure gas storage which indicated this technique could be feasible in some locations as long as gases were stored below normal hydrostatic pressures.

Simultaneous with the energy storage research, we undertook both theoretical and experimental studies of ways to reuse the stored hydrogen and oxygen as well as certain other energy conversion methods. The areas of effort in reconversion are as follows:

(1) Moderate temperature, high-pressure hydrogen-oxygen fuel cells using no noble metal catalysts were studied.

(2) The "aphodid" burner-turbine generator concept was studied (a method of burning hydrogen and oxygen in a long tube with an injected moderating water spray such that steam could be generated at any desired temperature and pressure).

(3) The field modulated generator system was studied (covered in an earlier paper in this meeting because of its obvious direct applicability to a wide variety of variable speed prime movers such as aeroturbines and unregulated high-speed gas turbines).

The results of the work on energy reuse were as follows:

(1) Fuel cells operating at pressures up to 200 atmospheres and 300° F were built. The effects of temperature and pressure were experimentally mapped and typical characteristics are shown in figures 4 and 5. All fuel cell work, as well as all electrolysis work, was done with nickel electrodes and no special catalysts. Rechargeable hydrogen-oxygen fuel cells employing a porous membrane (cylindrical geometry, fig. 6) made of calcia stabilized zirconia and sintered nickel electrodes with no noble metal catalysts were investigated extensively to study the effects of pressure, temperature, and membrane porosity.

(2) The aphodid burner (fig. 7) turbine generator system has never been built, but some years ago Dr. Stanley Brauser (a thermodynamicist then on our mechanical engineering staff) studied this at our request and concluded that efficiencies around 40 percent were obtainable (electrical equivalent Btu output over fuel Btu input). The difference between this and conventional plants is primarily the elimination of stack losses. Probably another few percent can be picked up by combining the field modulated generator (discussed earlier) with the aphodid burner. This would allow turbines to run at much higher speeds and probably at somewhat higher temperatures. These two factors yield higher turbine efficiency.

(3) The results on the field modulated generator have been reported; no other comments are required other than to say that it is fast approaching the stage of direct application to variable speed mechanical inputs.

(4) Finally, it should be noted that high-pressure hydrogen can be used as a basic ingredient in very efficient conversion of organic materials to various hydrocarbon fuels, including methane. We have begun to gather

technical material in this area, assisted by Dr. Wm. Crynes of our Chemical Engineering Department. Dr. Crynes is a recognized authority in coal gasification, and this area will be pursued as vigorously as resources permit.

The work described herein has, of course, been spread over several years. Much of it, initially at least, falls into the hazardous category. We have a specially built hazardous reaction facility, and, much of the work has been done there (figs. 8 and 9). That facility essentially provides an "explosion proof" chamber where reactions involving hydrogen and oxygen can be safely handled. We believe that we can formulate the rules for designing high-pressure moderate temperature electrolysis and fuel cell systems which operate safely. That, however, is a completely separate subject.

Finally, a complete wind generator energy storage system built about 5 years ago just to get an idea of the overall energy availability is shown in figure 10 on a 20-foot test platform at the airport laboratory facility. Figure 11 shows a close up, and figure 12 shows the details of the electrolysis system.

#### DISCUSSION

- Q: How do you foresee the potential eventual use of these types of systems? Do you ever see the day when they could possibly be domestically used. There is the safety problem with hydrogen.
- A: First, we're studying ways to use high-pressure hydrogen to hydrogenate organic materials to synthesize hydrozenes and methanes, and this looks very promising. So, one application that we have missed is a way of making synthetic vehicular fuels. It is not necessary to convert hydrogen to electricity to get a lot of good use out of it. Second, I'm a little nervous about using hydrogen as a domestic fuel. Looking at what we call our "Allison's boom room", the hazardous reaction facility, we have had some explosions there in a controlled environment. We think we now know how to handle hydrogen safely. At least, we haven't had any explosions for three years. Third, there is a lot of use that can be made of the hydrogen in heaters besides just converting it to electricity.
- Q: I wonder if I understood the efficiency figures you had correctly. The 68 percent you gave was power into the electrolyzer compared to power out of the fuel cell?
- A: When I said 60 percent overall, I meant kilowatt hours out of the fuel cell divided by kilowatt hours into the electrolyzer.
- Q: Any comparable figure for the electrolyzer and gas turbo combination?
- A: It's about 40 percent.
- Q: You raised the question of using hydrogen in the home. I have an article that says there are two or three miles of hydrogen pipeline in Germany that has been used for 20 or 30 years.

A: I didn't know they were using it for home use, but I'm intensely interested. The Germans have, of course, been handling high-pressure hydrogen in pipelines much longer than we have and are very experienced in it. I'm hopeful it can be used in the homes.

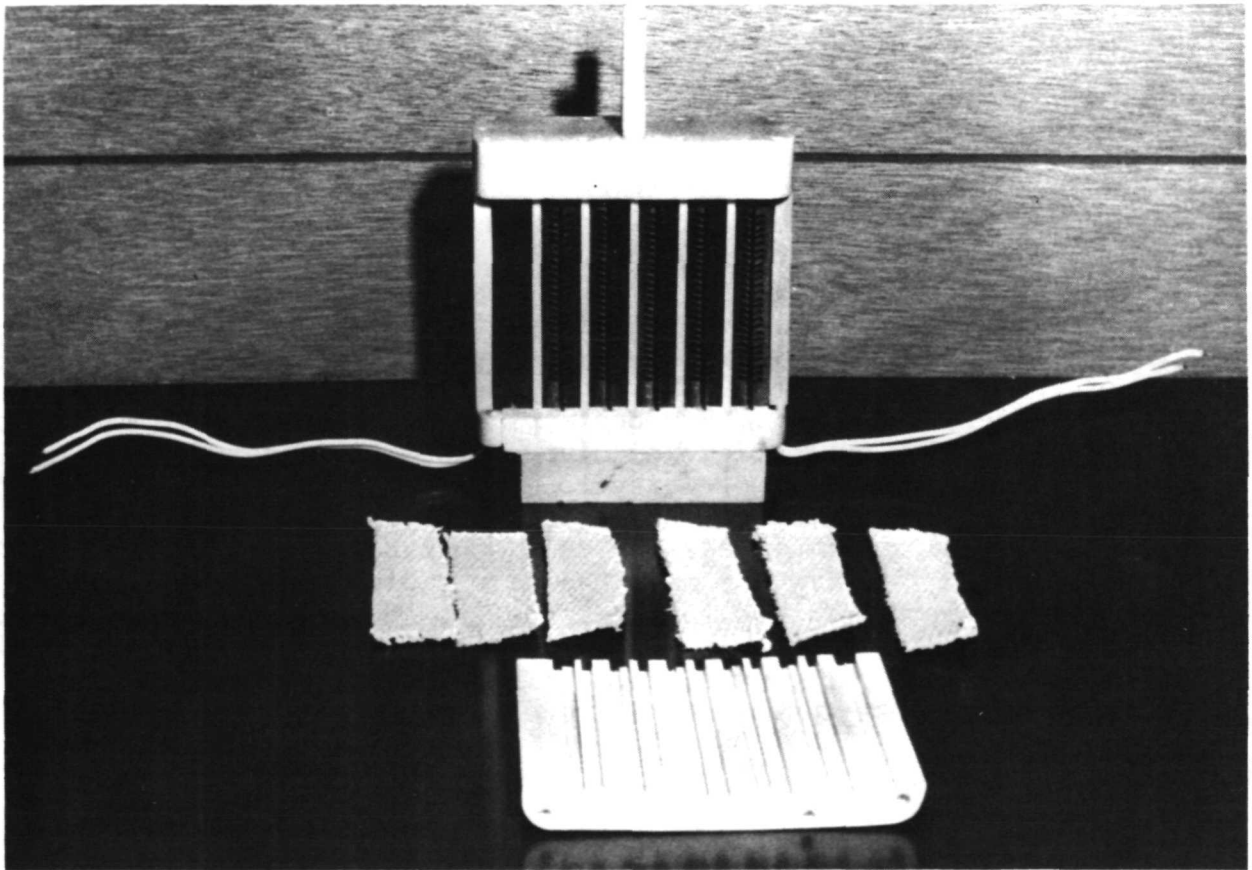


Figure 1. Photograph of six cell electrolysis module.

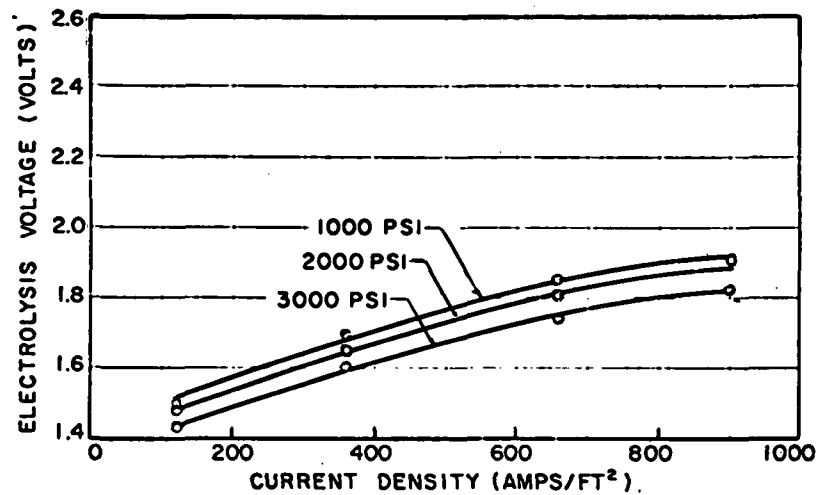


Figure 2. Effect of pressure on electrolysis cell performance at 300°F.

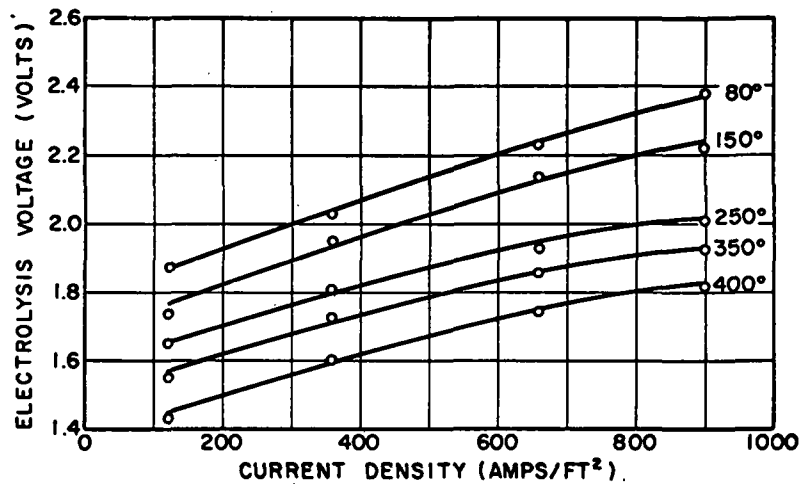


Figure 3. Effect of temperature on electrolysis cell performance at 2000 PSI.

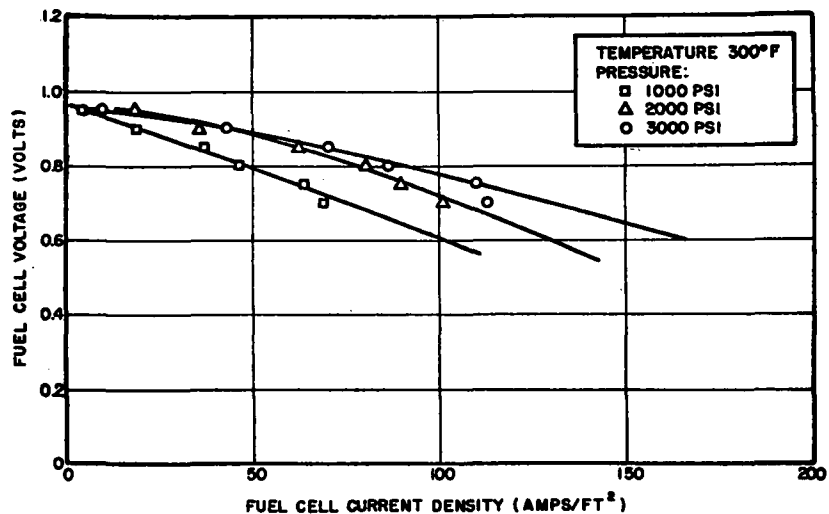


Figure 4. Effect of pressure on the fuel cell polarization curve; foam metal nickel electrodes with diamond lattice structure.

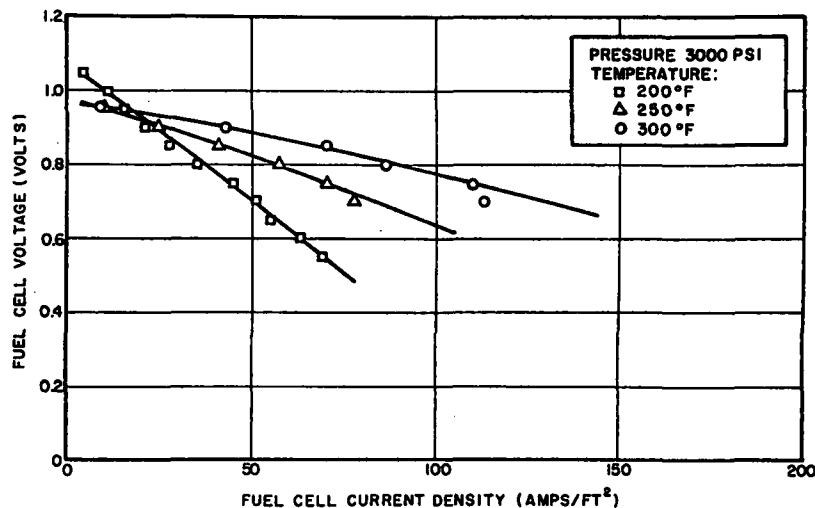


Figure 5. Effect of temperature on the fuel cell polarization curve; foam metal nickel electrodes with diamond lattice structure.

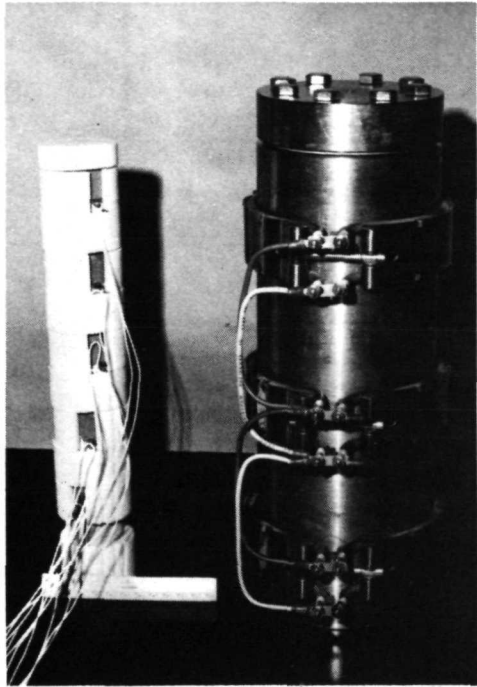


Figure 6. Photograph of a five cell battery of rechargeable fuel cells employing cylindrical porous zirconia membranes and sintered nickel electrodes.

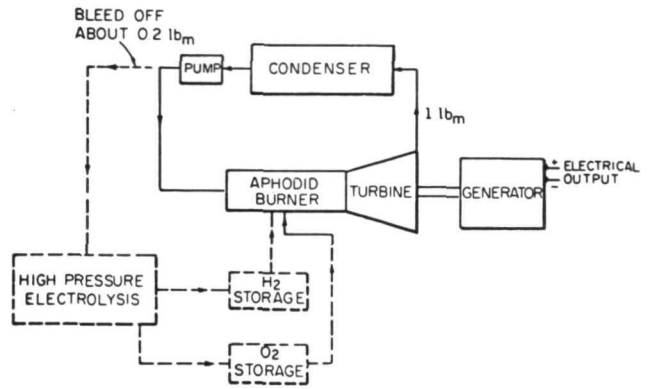


Figure 7. A simple Aphodid flow diagram.



Figure 8. OSU Hazardous Reaction Facility.



Figure 9. View of the hazardous reaction chamber of the hazardous reaction facility.



Figure 10. Photograph of the 500 watt experimental prototype wind energy storage system mounted on a twenty foot platform.



Figure 11. Close-up view of the experimental prototype wind energy storage system.

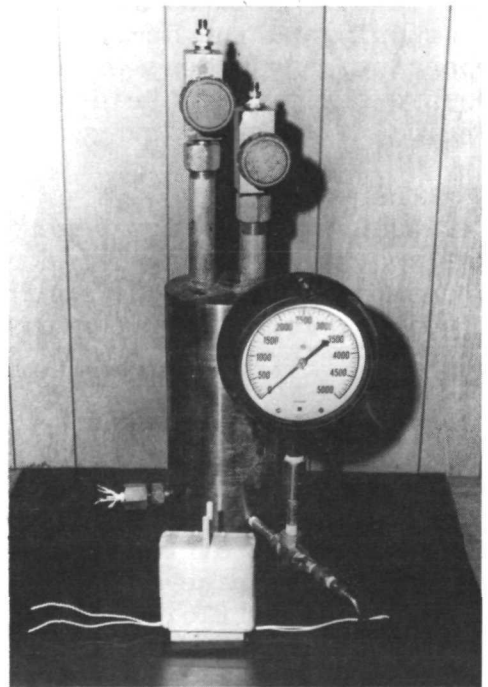


Figure 12. View of six cell electrolysis module with the high-pressure test chamber in background.