

## **PEMFC STACKS FOR POWER GENERATION**

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### **Abstract**

Industries promoting polymer electrolyte membrane (PEM) fuel cells for stationary and auxiliary power applications are receiving considerable attention because of the attractiveness of the primary markets, such as small, home-based power generation on the roughly 3 – 5 kW level. More recently, interest in auxiliary power applications down to about the 1 kW level has also been steadily increasing. Plug Power, LLC, a fuel cell manufacturer, is primarily pursuing the development of the home-based power systems. Technological advances in PEM fuel cells at Los Alamos National Laboratory (LANL) are of potential utility for the development of readily manufacturable, low-cost and high performance fuel cell systems operating at near-ambient reactant pressures. As such, the two parties are collaborating on addressing some of the more pressing needs as well as some longer term issues. The primary tasks involve the investigation of both stainless steel and composite bipolar plates, CO tolerant anodes, and novel fuel cell system operation schemes.

### **Introduction**

Fuel cells for home-based stationary power applications are attracting ever greater attention. Some of the possible reasons for this increased attention are the recent demonstrations and development successes of the PEM fuel cell, the deregulation of the utilities and the subsequent power difficulties in California this summer, and finally, the slow maturation and competitiveness of the transportation market for fuel cells. While the majority of funding and interest in PEM fuel cells has historically been for transportation applications, meaningful penetration of that market will be difficult for many years yet to come because the competitive technologies are well-entrenched and inexpensive. Despite the significant environmental advantages, fuel cell systems will still need to cost on the order of \$50/kW for transportation which will require at the least enormous production

levels. Until then, many of the fuel cell companies have been attracted to home-based stationary power as a possible fuel cell market that should still be sizable, should accommodate much higher unit costs and does not involve entrenched competition. Most domestic fuel cell companies have teamed up with utilities to explore such possibilities. The majority of home-based units will be designed to operate on natural gas because of the extensive distribution network in place. By installing home-based units, utilities can increase generation capacity without needing to site and license new plants or build new power lines, both of which have become ever more costly and problematic due to public resistance and tightening regulations. Natural gas suppliers might also be interested in the home-based systems because of the possibilities of competing in a new market and relieving their susceptibility to natural gas prices.

Operating the home-based system on natural gas will require a fuel processor to provide hydrogen to the fuel cell. The reforming and/or partial oxidation fuel processor reactions produce byproducts such as CO and CO<sub>2</sub>. If the CO is not removed from the fuel stream in some manner before it reaches the fuel cell it will severely affect performance, especially with standard anode designs. The typical strategy is to remove the CO through a series of additional steps, but removing the last tens of ppms can not always be routinely assured with typical systems. Therefore, anodes that can tolerate higher levels of CO than conventional electrodes are of interest to withstand excursions that may occur with start-up of the fuel processor or during variations in load levels. Another issue with the use of natural gas is the operating pressure of the fuel processor system. Most other hydrocarbon fuels are liquids that can be efficiently pumped to allow the use of a pressurized fuel processor. This decreases the fuel processor volume (and cost) and increases the pressure of the hydrogen delivered to the fuel cell stack, which alleviates dilution effects. However, domestic natural gas is typically delivered into the house at less than 1 psig. Compressing the natural gas incurs a considerable power penalty and requires an additional piece of expensive equipment. The preferable option is to operate a low-pressure fuel processor, however, the fuel cell anode will then need to operate at near ambient pressures. Anodes then need to be designed and optimized for both the low-pressure operation and CO tolerance.

The balance of the fuel cell system is inordinately complex and expensive. Conventional systems rely upon a multitude of subsystems, e.g., cooling, reactant humidification, water recovery, pressurization, etc., that introduce a parasitic power draw that compounds the size of the stack and/or lowers efficiency. If the subsystems can be combined or eliminated, often the lesser complexity and lower power draw more than compensate for any stack performance penalty once the entire system is taken into account.

Regardless of the fuel cell system or stack technology, one of the major limitations has been the bipolar plate technology. Historically, machined graphite plates have been the material of choice, but are clearly too expensive for mass production. The bipolar plates also need to be highly electrically conductive, durable, impermeable and corrosion resistant, a surprisingly difficult combination to realize. Metal hardware is of interest because of its toughness and the versatile fabrication options, but corrosion is a significant difficulty. Composites have therefore been the preferred option, but even then they have generally been too expensive.

## **Discussion**

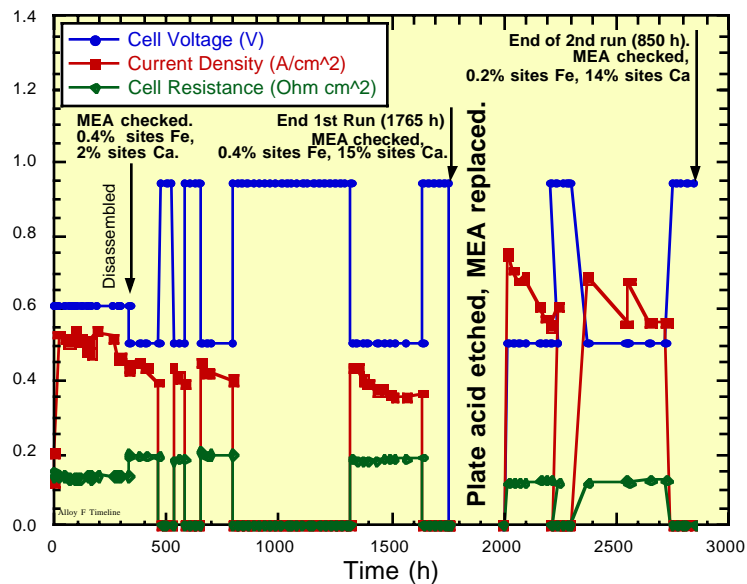
### **Metal Bipolar Plates**

As previously discussed here, most of our work with metal hardware in this program has focused on the development of non-machined low-cost bipolar plates based on the use of untreated metal alloy screens and foils (Wilson and Zawodzinski 1998 & 2000, Zawodzinski et al. 1998). In general, the hardware performed well in several fuel cell tests including a 2000 h life-test and appeared to be corrosion resistant, in that cell performance and the high frequency resistance

remained quite stable over the test period. When the membrane-electrode assembly (MEA) was subsequently examined by x-ray fluorescence (XRF) spectroscopy, it was found that metals such as iron and nickel were indeed present in appreciable quantities. While the cell performance was not yet unduly affected, significant losses can be expected over the much longer lifetimes that would be expected of stationary applications. While the membrane has some tolerance, eventually its active sites would be tied up by the polyvalent ions and ionic conductivity would be seriously impaired. Consequently, we commenced screening more “noble” stainless steel and nickel rich alloys that might provide better corrosion resistance than 316 SS but are still relatively low-cost. Many types of alloys have been developed for applications where common stainless steels such as 304 or 316 SS do not provide adequate corrosion resistance. In general, the compositions of these alloys are similar to their stainless steel or nickel-base counterparts except that certain stabilizing elements, such as nickel, chromium and molybdenum, are added and/or are present in much higher concentrations in order to obtain desirable corrosion properties. Different combinations of these elements and their concentrations can dramatically change the nature of the alloy and thus, alloy compositions are usually tailored for quite specific applications, such as marine water service. This poses a problem in choosing suitable materials for fuel cells because of the variety of conditions present that are all conducive to corrosion yet are very different in nature, i.e. chemical and electrochemical oxidizing and reducing environments, humidity, and possibly slightly acidic environments.

For example, nickel, which is common to all of these families of alloys, provides corrosion resistance in neutral and reducing environments and is essential to prevent chloride stress corrosion cracking. Thus, for applications such as seawater or caustic service, a high Ni content is required and most of the nickel-base alloys have been developed for these types of applications. In neutral to oxidizing media, however, a high chromium content (which is often accompanied by the addition of molybdenum) is necessary. Many of the stainless steel alloys have been developed along this vein and are used in a variety of corrosive environments, i.e. nitric acid service. Since both oxidizing and reducing conditions exist in a typical fuel cell environment, we screened a number of stainless steel and nickel alloy samples representing several categories of corrosion-resistant materials as possible improvements to 316 SS. The alloys were evaluated using individual immersion testing in pH 2 and 6 sulfuric acid solutions held at 80°C that were either sparged with hydrogen or air to simulate anode and cathode conditions, respectively. Although severe, the pH 2 conditions tend to accelerate corrosion of the materials and thus differences in the corrosion resistance of numerous alloys can be assessed relatively quickly (on the order of a few weeks). As a result, only the most promising alloys need be made into bipolar plates and tested in fuel cells, which is a time-consuming and much more expensive process. The “corrosion” was quantified by gravimetric weight loss and by measuring the metal ion uptake in Nafion membranes placed in the solution during the test. The latter is used to anticipate the severity of ion uptake in operating fuel cell membranes. As reported last year, roughly a half dozen promising alloys were identified, both of the stainless steel and of the nickel-based types. The preferred Ni-based alloys were intriguing because although their pH 2 corrosion tolerances were only mediocre, their pH 6 tolerances were the best surveyed.

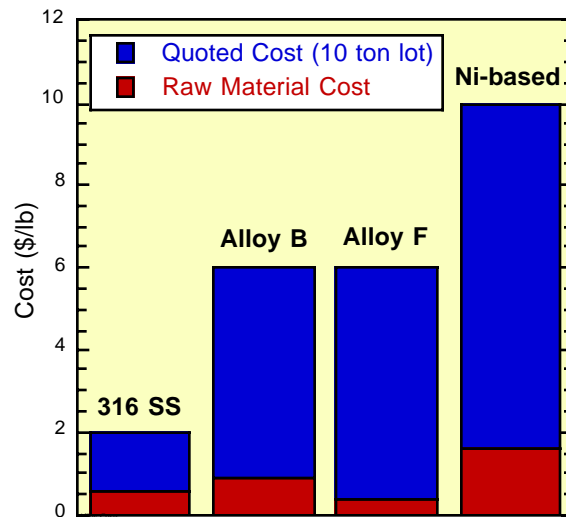
Consequently, over the past year, the down-selected alloys were tested on the anode side of 50 cm<sup>2</sup> pressurized and humidified PEM fuel cells. Unfortunately, the Ni-based alloys showed appreciable corrosion after only a short time in the fuel cells. Even though the cell effluents were in the pH 6 range, the fuel cell is enough different from the immersion testing that the pH 2 results appear to be a better indicator. Nevertheless, two of the stainless steel-type alloys, described as “B” and “F”, provided very promising results. In order to see how the cells responded to optimum as well as severe conditions each cell was put through cycles of operation at 0.5 V and at open-circuit voltage (OCV), which was about 0.94 V. During the course of operation, the cells underwent shutdowns due to unplanned circumstances such as power outages as well.



**Figure 1 — Timeline for an Alloy F Fuel Cell Anode Corrosion Test.**

For example, an alloy F test is shown in Figure 1. The cell incurred a total of approximately 1766 h at 0.5 V operation and 1253 h at open-circuit voltage (OCV). Extensive OCV conditions are included as the cell conditions can be particularly aggressive for many alloys. After the first 1151 h of 0.5 V operation and 1068 h at OCV, the MEA was analyzed by XRF and found to contain calcium and only a trace of iron. More susceptible alloys will result in a more extensive array of metal ions and a higher degree of exchange. The calcium probably comes from the water despite the use of deionized water and the iron may have come from other carbon components in the fuel cell where we have detected iron in the past. However, the high frequency resistance (HFR) of the cell was relatively high possibly due to extensive passivation layers on the untreated alloy's surface. Passivation layers are less conductive than a clean metal surface and thus increase its resistance, but are beneficial in terms of promoting corrosion resistance.

To test this, the alloy was acid-etched to strip off any passivation layers and was put back into the fuel cell with a new MEA. The HFR lowered to a reasonable value suggesting that passivation layers were indeed the cause of the higher values previously obtained. The cell was operated for another 615 h at 0.5 V and 185 h at OCV before the MEA was analyzed and again found some calcium and only a trace of iron. Thus it appears that removing the passivation layers was not detrimental, the material is still corrosion resistant. Tests for a second alloy, "B", were performed for roughly similar durations. As with the "F" tests, the MEA contained calcium and a trace amount of iron. Though roughly comparable, the results of B are more promising because the alloy gave a very low HFR from the start making pretreatment unnecessary. In terms of bipolar plates, any treatment steps that can be eliminated result in lower costs.



**Figure 2 — Comparison of Raw Material and Quoted Costs for Various Alloys.**

A natural concern is the cost of the more “noble” stainless steel type alloys. While some of these alloys may use several percent of relatively exotic elements, the primary factor affecting costs is typically demand. Shown in Figure 2 is a bar-chart comparing the costs of Alloys B and F with 316 SS and a generic Ni-based alloy. Also shown are the raw material costs calculated from recent market prices for the various constituent elements. The quoted costs for 10 ton lots of B and F are similar even though the raw material costs of one is more than twice the other. The single biggest factor affecting the raw material cost is the amount of nickel used, as demonstrated by the cost of the Ni-based alloy. Also illustrated is the high mark-up of these specialty alloys over the raw material cost compared to 316 SS. In short, alloys B and F should not be intrinsically any more expensive than 316 SS, but it will require large-scale production in order to get a price break on the alloying cost. Both are available in strip and plate form, however, alloy B is presently available in some foil thicknesses as well.

Due to these promising results cathode plates of each alloy will be tested. If cathode testing is successful, alloy B, which is available in a variety of forms and provides a low cell resistance without pretreatment is presently the favorite to utilize in future short stack testing. Stack testing of promising alloys is essential as success on the single-cell level does not necessarily promise success on the stack level, as possible shunt and/or stray currents can result in significantly more challenging environment. Future work will also include immersion testing of alternative untreated alloys that come from the same respective families as B and F, in case even more promising variations can be identified.

### **Composite Bipolar Plate Materials**

Composite materials offer the potential advantages of lower cost, lower weight, and greater ease of manufacture than traditional graphite or coated metal plates. For instance, flow fields can be molded directly into these composites, thereby eliminating the costly and difficult machining step required for graphite. Most of the composites used in fuel cell bipolar plates have employed graphite powder in a thermoplastic matrix such as polyethylene, polypropylene, or, most commonly, poly(vinylidene fluoride) (PVDF). Unfortunately, PVDF is relatively expensive, and any thermoplastic composite must be cooled before its removal from a mold, resulting in long cycle times. On the other hand, thermosetting resins (e.g., phenolics, epoxies, polyesters, etc.) generally

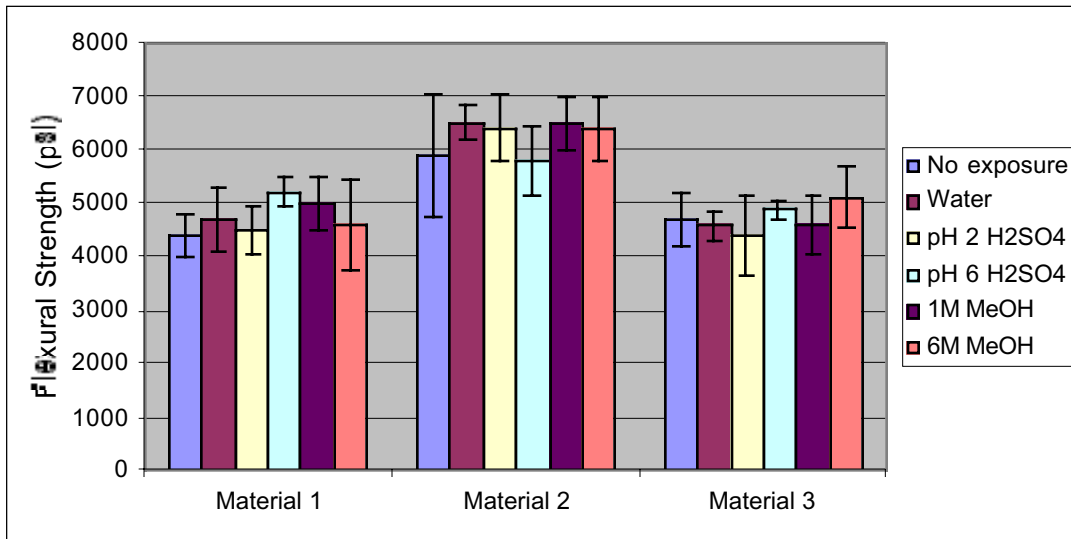
offer shorter process cycle times than thermoplastics because, once cured, they become sufficiently rigid and can be removed from the mold while still hot. Furthermore, injection molding, or at least injection compression molding may be possible with the “wet” (albeit thixotropic) resin mix which would be very difficult if not impossible with the dry thermoplastic mixtures, which are probably limited to compression molding. In either case, cost-effective mass production would tend to be more readily achievable with thermosets rather than thermoplastics because of their shorter cycle times. With the proper combination of resin additives and temperature, a compression molded thermoset composite can cure in comfortably less than about two minutes, resulting in cycle times an order of magnitude less than those required for thermoplastics. One particular family of thermoset resins, vinyl esters, seems especially well-suited to bipolar plates (Busick and Wilson 1998). Vinyl esters are methacrylated epoxy difunctional polyesters, and as such are often described as a cross between polyester and epoxy resins. In addition to being noteworthy for their excellent corrosion resistance, vinyl esters are lightweight, strong, tough, and commercially available at surprisingly low cost. By capitalizing on these properties of vinyl ester resins, we have developed new material formulations for producing low-cost, high-performance, easy-to-manufacture composite bipolar plates.

The most widely used conductive filler for composite bipolar plates is graphite powder and it is employed in the vinyl ester composites described here as well, although early tests revealed that the choice of graphite powder influences the conductivity of molded parts. Thus, the relationship between filler loading and electrical conductivity appears to depend somewhat on graphite particle size and particle size distribution. We have identified a particular type of graphite powder with a fairly narrow particle size distribution that offers relatively high conductivity for a given volume fraction and is reasonably easy to combine with the liquid resin to form a homogeneous mixture.

Early development with Plug Power resulted in relatively crude but successful formulations that provided plates that were stronger and tougher than other commercially available composites and conceivably much less expensive due to the lower cost binder and the faster cycle times. Fuel cell testing at Plug Power provided results that were comparable to machined graphite in their hardware as reported here last year. Compounders, companies that specialize in formulating composite resin mixtures, Premix, Inc. and Bulk Molding Compounds, Inc. (BMC), refined and improved the formulations using their proprietary additives and expertises. Plug Power has subsequently obtained good stack results with plates molded to shape with compounds provided by these companies. Our primary role became characterizing the properties of the molded plates (conductivity, corrosion-tolerance and mechanical properties) to assist the compounders in optimizing their formulations. Since, Premix and BMC have sampled or sold products to a number of potential customers. Consequently, our role is diminishing and will probably cease altogether with the exception of legacy issues such as intellectual property, etc.

Over this past year, the major issue addressed was the effect of exposure testing under aggressive conditions on the mechanical properties of the composites. The primary concern is that although the “ester” in vinyl ester is not a component of the polymer backbone, it will conceivably hydrolyze nonetheless (a weakness with polyesters under such conditions) with unknown consequences on the durability of the plates. Naturally, the hydrolysis rate depends upon the presence of water. As such, some samples were immersed in 1 or 6 M methanol not only to improve wetting of the plate and hence exacerbate the hydrolysis problem, but also to gauge the suitability for the composites for direct methanol fuel cells (DMFCs) should a market-viable product ever be developed. As such, flat-molded plaques (nominally 0.1 in. thick) of promising bipolar plate materials were provided by Premix, Inc. for the exposure testing. Material 1 contained 75% graphite powder in a proprietary formulation of the thermosetting resin and various additives. Material 2 contained 65% graphite powder in a resin formulation identical to that of Material 1. Material 3 contained 75% graphite in a resin that is a possible alternative to the “preferred” resin used in Material 1 and Material 2. After the electrical conductivities of the materials were measured,

rectangular mechanical test coupons were cut from the plaques. Six coupons of each material were immersed in each of five different liquids for 1000 hours at 80°C. These liquids (water, 1M and 6M methanol, and pH 2 and pH 6 sulfuric acid) ranged from expected to unduly aggressive environments for hydrogen or direct methanol fuel cells. Small squares of Nafion 112 membranes were immersed with the samples; following the 1000-hour exposure period, the membranes were analyzed using x-ray fluorescence spectroscopy to identify any ionic leachant species. All of the exposed mechanical test coupons, plus six unexposed coupons, were tested for flexural strength according to ASTM D638.



**Figure 3 — Flexural Strengths of Test Samples after Aggressive Immersion Testing.**

The XRF analysis of the Nafion membranes immersed with the composite samples indicated the presence of calcium. This was to be expected, since previous immersion tests conducted by both LANL and Premix revealed similar results. Calcium is present in the ash component of the graphite powder, and is able to leach out of finished plates when they are immersed in liquid. When the test liquid is not circulated or changed, noticeable amounts of calcium can accumulate. However, in an operating fuel cell with the liquid continuously flushed, calcium does not appear to be any greater of a problem than with machined graphite plates.

The results of the flexural strength tests are shown in Figure 3. There is a significant difference in strength between Material 1 and Material 2. This difference was expected, since the materials contain the same resin binder but different relative amounts of resin and graphite. With its lower graphite content, Material 2 is stronger than Material 1 since most of the strength of a particulate composite is derived from the resin binder. However, the lower graphite content of Material 2 also lowers its electrical conductivity to a level that is currently considered "borderline acceptable" for bipolar plates. Based on a comparison between Material 1 and Material 3, the preferred and alternative resins are equivalent in terms of flexural strength imparted to the bipolar plate. It is important to note that the test coupons were cut from molded plaques, not directly molded to shape. This introduces edge roughness effects in the 3-point bending test. The flexural strength of an uncut, molded-to-shape plate is anticipated to be 10-20% higher than the values shown in Figure 3.

A prime motivator for investigating various alternatives to the "preferred" resin binder was the potential susceptibility of the resin to chemical attack, especially when facilitated by methanol. However, for each material, the flexural strengths of the exposed samples are at least equivalent to the strength of unexposed samples, within experimental scatter. Thus, the most important and encouraging result of this study is that the strengths of the various materials investigated are

unaffected by exposure to various conditions including those much more aggressive than a fuel cell environment. Clearly, any chemical attack or hydrolysis that may be occurring is not affecting the structural component of the matrix.

## CO Tolerant Anodes

The majority of home-based stationary power systems will need to be designed for operation on natural gas, primarily due to its extensive distribution network. The simplest home-based units will use near-ambient pressure steam reforming to avoid the requirement of pressurizing the feedstock when converting the natural gas to a hydrogen rich fuel stream. The thermodynamic reaction equilibrium at the high temperature steam reforming (e.g., 700°C) yields a roughly 10% concentration of CO by-product. As a result, the reformat is relayed through high and low temperature (HT and LT) water-gas shift reactors to further lower the CO concentration. Since even 0.1 % CO (1000 ppm) is easily enough to thoroughly poison the fuel cell anode, the effluent from the LT shift reactor is sent to a preferential oxidation (PROX) reactor. Here, the CO is selectively oxidized using oxygen from injected air to lower the CO to a level that can ideally be tolerated by the fuel cell. Unfortunately, it is difficult to assure sufficiently low CO levels so air bleeding into the fuel cell stack anode inlet is used to increase the anode tolerance. Another means of increasing CO tolerance is merely by increasing cell temperature, which lowers the CO sticking coefficient. However, it is not possible to increase the operating temperatures much over the standard 80°C with near-ambient pressures. In any case, the amount of bleed air required to recover performance as well as the upper level CO tolerance of the anode is strongly dependent upon the anode design and catalysts.

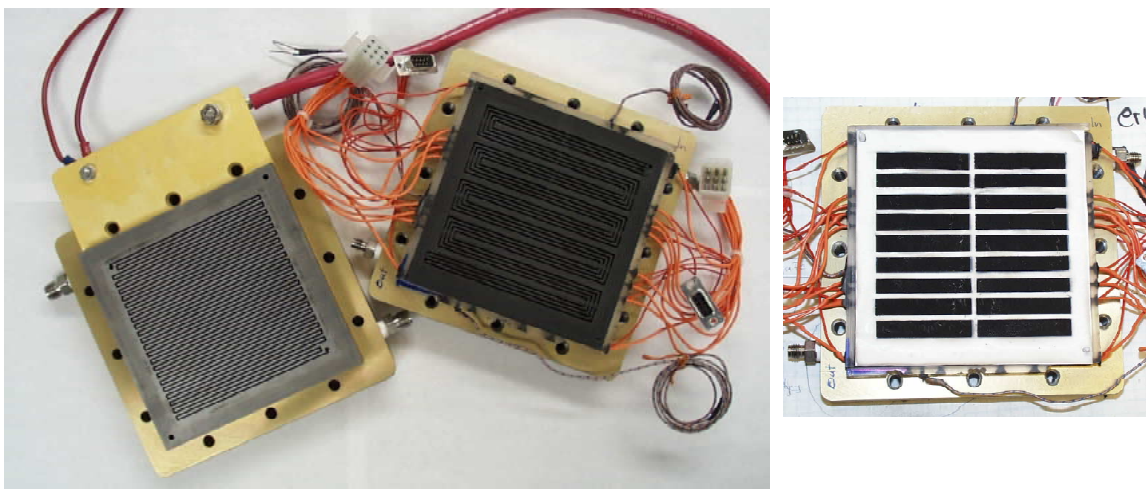
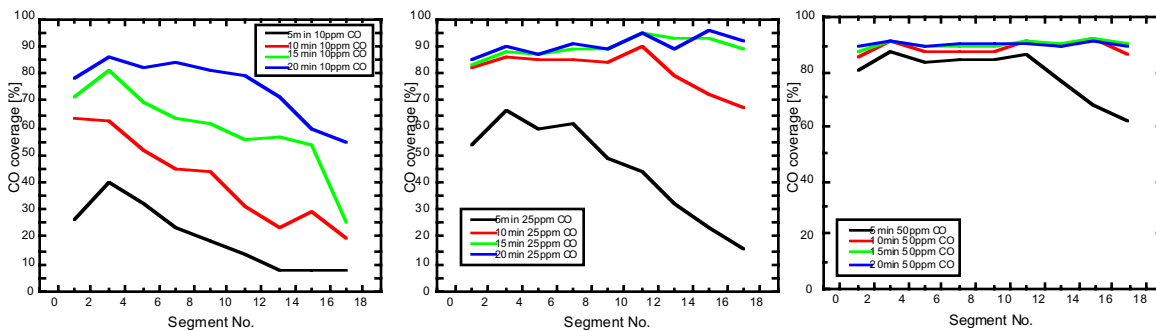


Figure 4 — 100 cm<sup>2</sup> Segmented Cell Hardware and a Segregated MEA





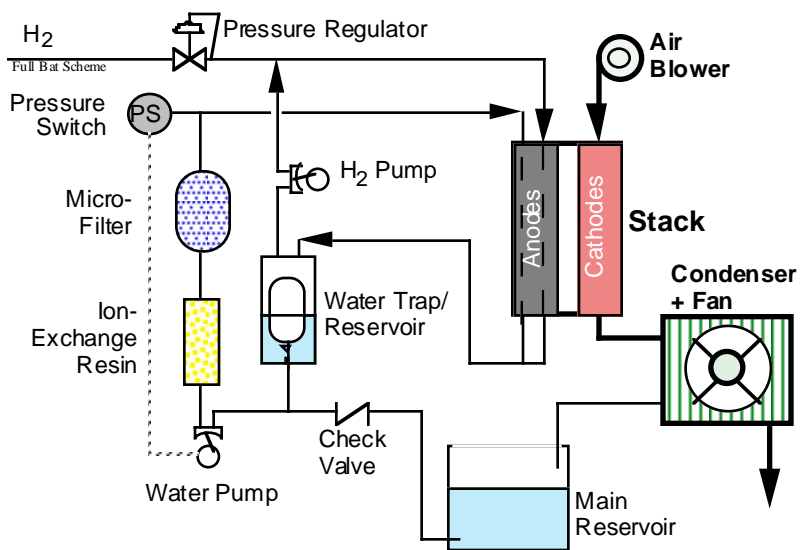
**Figure 5 — CO Coverages Along the Anode Flow-Field as Functions of Time and Concentration**

At Los Alamos, we previously developed a "reconfigured anode" (RCA) for pressurized transportation applications that demonstrated substantially increased anode tolerance compared to conventional anodes. Last year, we showed results for ambient pressure attained in a LANL 50 cm<sup>2</sup> single cell at Plug Power which surprisingly showed very modest losses compared to a neat hydrogen stream. Unfortunately, as is so often the case, it has not been possible to replicate the small cell results on larger single cells or in stacks with either ambient or pressurized anode operation. Characterizing the dynamics of the CO poisoning and the RCA within the cell is consequently important in order to understand the link between the small and the larger cells and stacks. The most straightforward method of elucidating the various mechanisms as the reactant progresses through the cell is possibly to use a "segmented" fuel cell. In such a cell, one of the flow-field plates of a conventional 100 cm<sup>2</sup> single-cell is sectioned into numerous small, electrically isolated sections to provide numerous small individual fuel cells within the same flow-field plate. It is consequently possible to map the performance over the active area and "follow" the effects of CO poisoning as the reactant gasses pass through the flow-field. The segmented cell used over the past year is shown in Figures 4a and b. Unfortunately, various difficulties with the design and electronics allow the segments to cross-talk an undue amount at higher current densities, so the most useful experiments are to perform voltammograms on each segment to effectively "titrate" the CO adsorbed on each segment as a function of time and CO concentration. The series of graphs in Figure 5 qualitatively portrays one such family of curves on a conventional (non-RCA) anode. Not surprisingly, at lower CO concentrations the upstream segments shield the downstream to a large degree but are quickly overwhelmed at the higher concentrations. On the other hand, the amount of CO gettered appears to be greater than attributable to the active area, which may not be a real effect due to the cross-talk and other problems with the experimental set-up. Consequently, a new segmented cell is being designed and fabricated to hopefully perform better and provide additional features, such as gas sample taps and thermocouples at each element. The segmented cell approach is of interest not only to characterize CO poisoning but to also generically understand the effects of various operating conditions (e.g., humidity levels and temperatures) and configurations (e.g., counter- vs. co- vs. cross-flow) and flow-field designs (and their effects on CO tolerance).

### Adiabatic Stack Operation Scheme

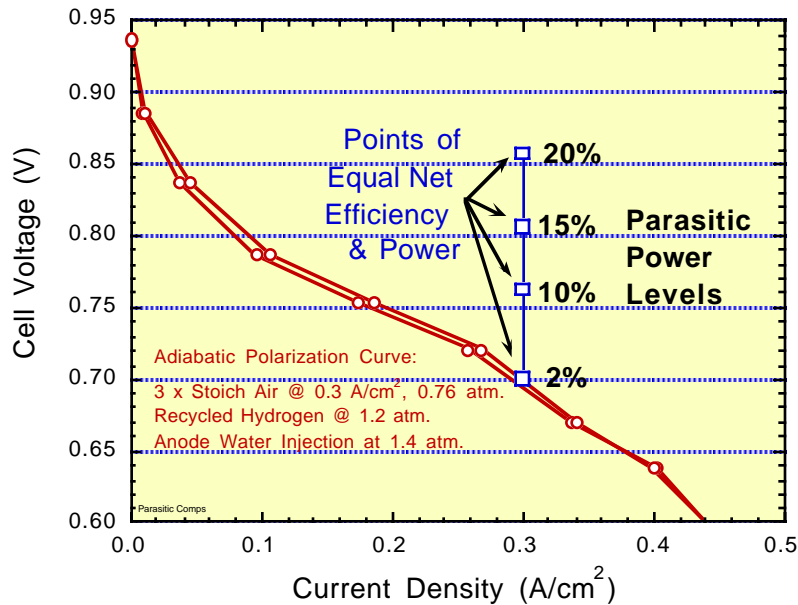
Near ambient pressure operation is of interest for the air or cathode side for much the same reason as the anode side, that is, to minimize parasitic power losses and lower the component costs. If pressures can be kept low, a blower can be used to provide the air flow through the fuel cell. While not particularly efficient, a blower is obviously much less expensive than a turbine or positive displacement compressor, and with very low pressures, the PV work required is minimal and the

device efficiency is not particularly critical. Since the cathode kinetics are roughly first order with respect to oxygen partial pressure, the stack power densities are not as high as with the pressurized cells. However, we demonstrate below that once the parasitic losses are taken into account, the net power densities are not very different. A number of issues arise with very low-pressure operation. Low-pressure operation often results in drier operating conditions due to both lower current densities (less water produced) and the higher water vapor volume fractions (more water removed with the air effluent compared to pressurized). As such, the effectiveness of the membrane hydration scheme becomes more significant at the lower pressures. The technique for direct liquid water hydration of the membranes that we use (Wilson 1999) appears to have advantages over the classical means of cell hydration, namely, reactant humidification. Avoiding reactant humidification also eliminates the pressure drop required to force the reactant air through the humidification module, which further decreases the parasitic power requirements. A consequence of introducing ambient temperature air into the humid environment provided by the direct liquid water hydration is that the stack is readily evaporatively cooled. Cooling plates, coolant and radiators, etc., are then eliminated which further simplifies the system. Since the airstream heats up substantially as it passes through the stack, a temperature gradient is established from inlet to exit sides. In contrast to typical “isothermal” stack designs, this temperature increase is encouraged in order to avoid condensation and the two-phase flow pressure drop problem. For such reasons, this approach is described as “adiabatic” operation. This past year, we have demonstrated the utility of the adiabatic approach on a roughly 1.5 kW level. The system was operated with less than 2% parasitic power and full water self-sufficiency at a 56% overall system efficiency and 350 W/L net power density.



**Figure 6 — Schematic of the Adiabatic Stack System**

Over the past year, the adiabatic stack system was also further simplified. A current schematic of the roughly 1.5 kW system is depicted in Figure 6. Water recirculation through the stack (for the direct liquid hydration) and make-up from the ambient-pressure main water reservoir are now accomplished using a single water pump in conjunction with a pressure switch and float valve. With this scheme, a second pump, liquid level sensor and motor controller are eliminated or replaced by lower-cost and non-powered components.



**Figure 7 - Polarization Curve Illustrating the Effect of Parasitic Power on Net Efficiency and Power**

The less than 2% parasitic power level is of critical importance to allow the modest performance of the adiabatic stack to compete favorably with higher pressure fuel cell stacks in terms of net power density and efficiency. The parasitic power significance is illustrated in Figure 7. Here, a polarization curve depicting the rather modest performance of the adiabatic stack is depicted. However, for a higher parasitic power (e.g., pressurized) system to match the net efficiency of the adiabatic stack, it must operate at a higher cell voltage. For example, if a competing system has a 15% parasitic power level (quite optimistic for a 30 psig stack, reasonable for a 2 – 3 psi stack with no PV recovery), then it must operate at about 0.81 V/cell to attain the same net efficiency. The unit cells in the competing stack will actually need to be thinner to achieve the same net power density, because the stack must also accommodate cooling plates, etc.

## Conclusions

Commercialization of home-based stationary power PEM fuel cells will require reliable and inexpensive components and systems. Consequently, a common theme uniting the various tasks and efforts in this program is that they are all oriented towards overall system simplicity, with the belief that ultimately the long term commercial viability of fuel cell systems will depend upon their simplicity (and hence cost and reliability). Major steps to realizing these criteria can be achieved with the development of low-cost and reliable bipolar plates, stable and effective CO tolerant anodes, and highly efficient and simple fuel cell systems. Clear progress has been made this past year in meeting these objectives, particularly with the commercial attention enjoyed by the composite bipolar plate approach and the low parasitic power system demonstration of the adiabatic stack. While not quite as fast paced as the above tasks, we are developing the fundamental underpinnings for future advances in the more challenging metal alloy bipolar plate and CO tolerant anode tasks.

## Future Work

If upon further testing promising cathode results are obtained in the single cell tests with Alloys B or F, the next step in the metal alloy bipolar plate effort will be to procure foils appropriate for the fabrication of an internally manifolded short stack. This step is necessary to definitively demonstrate the viability of uncoated metal alloy fuel cell hardware because of the additional corrosion challenges that a stack presents such as stray and shunt currents. Because the technology is now basically in commercial hands, the composite bipolar plate component of the project is winding down, although the work involved with the other tasks more than make up for the amount of resources made available. The work on CO tolerant anodes based on the LANL reconfigured anode approach will enter a more fundamental phase of understanding in order to better design and optimize anodes for larger cells and stacks. The segmented cell will be instrumental in characterizing the poisoning and mitigation processes. While the reconfigured anode CO mitigation strategies have improved tolerance substantially, the overall system is remarkably complex merely to supply low CO levels. Entirely new CO tolerant anode approaches are needed and will be considered. Cost will always be a critical issue even though the net performance levels of the adiabatic stack system compare favorably with more complex systems developed elsewhere, so we would like to increase the power produced per cell at the 0.7 V/cell level. We anticipate that we may be able to increase the current density (i.e., power) about 50% using new flow-field and gas-diffusion structures (plus some additional improvements), which obviously decreases costs/kW substantially. While the system is already quite simple, the next step to work on in further simplifying the system is to eliminate the hydrogen recirculation pump. This is necessary to flush condensate from the anode side, but judiciously altering the anode water supply scheme may alleviate the condensation difficulties.

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