Low-Cost Multi-layer Fabrication Method for Solid Oxide Fuel Cells

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Objectives

- Evaluate commercial binding agents for rapid catalysis of layered solid oxide fuel cell (SOFC) structures.
- Determine binder reactivity with state-of-the-art SOFC materials.
- Determine performance of SOFC single cells using new structures.
- Design a pilot manufacturing plant and estimate the potential economic impact of the new process.

Key Milestones

- Preliminary Cost Studies completed July 2000.
- Chemical Compatibility Tests, completed December 2000.
- Single Pass Printing completed July 2001.
- 3-Dimensional Printed Structures completed March 2002.

Abstract

Technology Management Inc., (TMI) has evaluated the advantages and potential economic impact of using a multi-pass screen printing fabrication process to make planar solid oxide fuel cell stacks. During this program, several catalyzed binder systems were considered. Preliminary screening experiments identified four binder systems for further evaluation. Anode, cathode, and seal inks were formulated using these binders. Reactivity of the binder with the catalyzing method and fuel cell materials was evaluated. Cell tests indicated that the catalyzed binders did not negatively impact cell performance. Tests demonstrated single cell performance comparable with cells fabricated using standard technology. The use and feasibility of non-uniform patterns were also demonstrated for the anode and cathode. The economic evaluation indicated that overall, a significant reduction in production cost could be achieved. The largest savings were realized by reducing the cost of capital equipment required.

Binder Evaluation: A key milestone was identifying a polymer system compatible (i.e., non-contaminating) with SOFC materials and having desirable rheological and curing properties. Broadly, the problem can be analyzed as follows: 1) rheology, 2) decomposition and byproducts, and 3) curing rate.

The factors affecting rheology were straightforward and included:

- binder viscosity
- solids loading
- particle size
- particle/binder interaction (surface potentials)

Because the SOFC operates at high temperature (> 800°C), binder decomposition was a consideration. The ink vehicle must decompose completely and preferably leave no residue. Of particular concern are contaminants from decomposition such as sodium, phosphorous, and sulfur, elements frequently included as counter-ions in dispersants and surfactants. These ions can react adversely with some fuel cell components if used indiscriminately.

A rapid curing rate was required. Catalyzed polymer systems are known to set-up or harden quickly due to polymerization cross-linking reactions. Some SOFC materials, notably sub-micron $LaMnO_3$, have the potential to interact with the polymer matrix and create activated carbon centers. The carbon centers are highly reactive and bond to adjacent polymer molecules leading to a rigid, heavily cross-linked matrix. This interaction must be minimized to avoid premature cross-linking and subsequent ink solidification on screen-printing equipment, which fouls the printing operation.

Using these criteria, a number of binder systems were selected and evaluated using simplified screening tests. After rank-ordering, the top systems were re-evaluated in more detail, including direct electrochemical testing. Electrochemical testing, such as that shown in Figure 1, was conducted to determine the impact on SOFC performance. While there were no "perfect" candidates, one system was accepted and chosen, based on the best compromise of performance and curing rates.

There are many practical challenges to creating a new processing technique. Examples include: alignment and reproducibility. After considerable development, high quality, multi-pass printing was demonstrated in 2001. An example of multi-pass seal printing is shown in Figure 2. These test results clearly indicate that the approach could produce components as consistent in quality and performance as those produced using more traditional approaches.

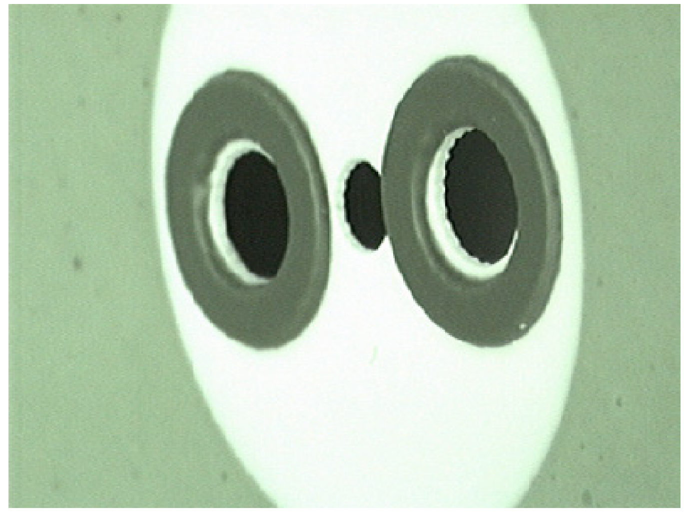

Figure 2. *Multi-layer printed seals.*

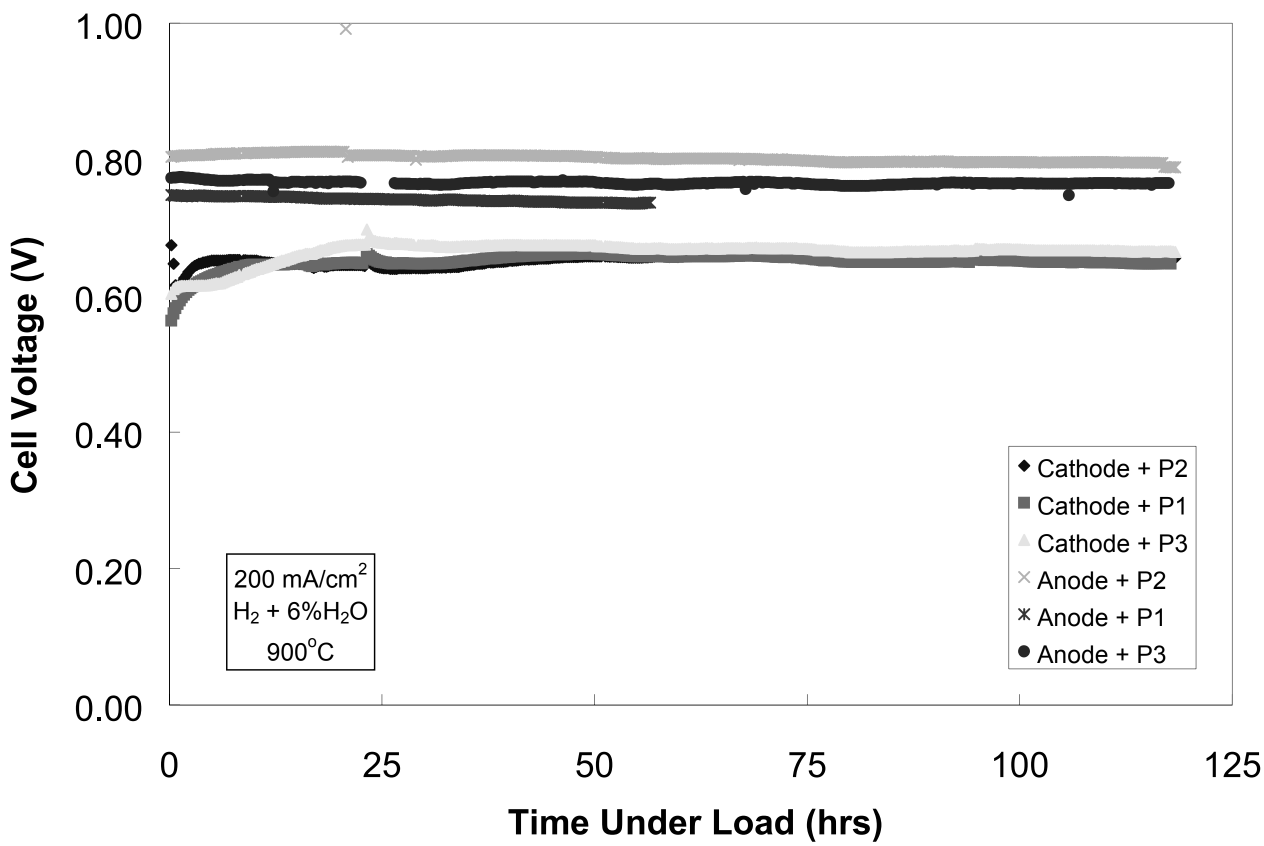

Figure 1. *Cell performance for several binders (anode and cathode).*

Cost Estimates: The TMI fuel cell stack consists of seven components: electrolyte, anode, cathode, anode seal (x2), cathode seal, and separator. The multilayer technology developed during this program is projected to have a major cost impact on five of the seven components: anodes, cathodes, and all three seals. Component cost savings will result from a combination of factors, including the following:

- reduced electrode layer thickness for desired pressure drop
- reduced average density of anodes and cathodes
- reduced fabrication costs (lower capital and labor)
- improved yields

Savings Over Current Methods: Projecting these cost savings (over using current TMI technology as a base case) depends strongly on annual manufacturing volume, since as more automation is employed at higher production rates, savings in raw materials becomes progressively more significant. Using a detailed cost analysis model, the values in Table 1 were computed.

Thus the five components cited are expected to cost only about half as much at a commercial volume of 10 MW/yr and less than one-fourth as much when volume reaches 1000 MW/year.

Stack manufacturing costs include two other cell components (electrolytes and separators) as well as the cost of assembly and quality control testing. Figure 3 shows an example of a stack assembly work cell, designed to produce finished stacks based on the multi-layer printing process.

The savings (in percentages) when employing multi-layer technology for the entire process are shown in Table 2. The reduced cost of the five components combine to reduce overall costs by ~ 13% at low volume, and by more than 32% at higher quantities (above 1000 MW/year). Because stack replacement costs are expected to be an issue early on in the development, these costs are of even more importance.

Table 1: Stack Cost Analysis

Stack MW/year	Multi-layer/Base Case: 5 Components Cost Ratio
10	50%
30	36%
100	30%
300	26%
1000	24%
3000	23%

Table 2. Stack Cost Ratios

Stack MW/year	Multi-layer/Base Case: Stack Cost Ratio
10	87%
30	83%
100	78%
300	73%
1000	68%
3000	64%

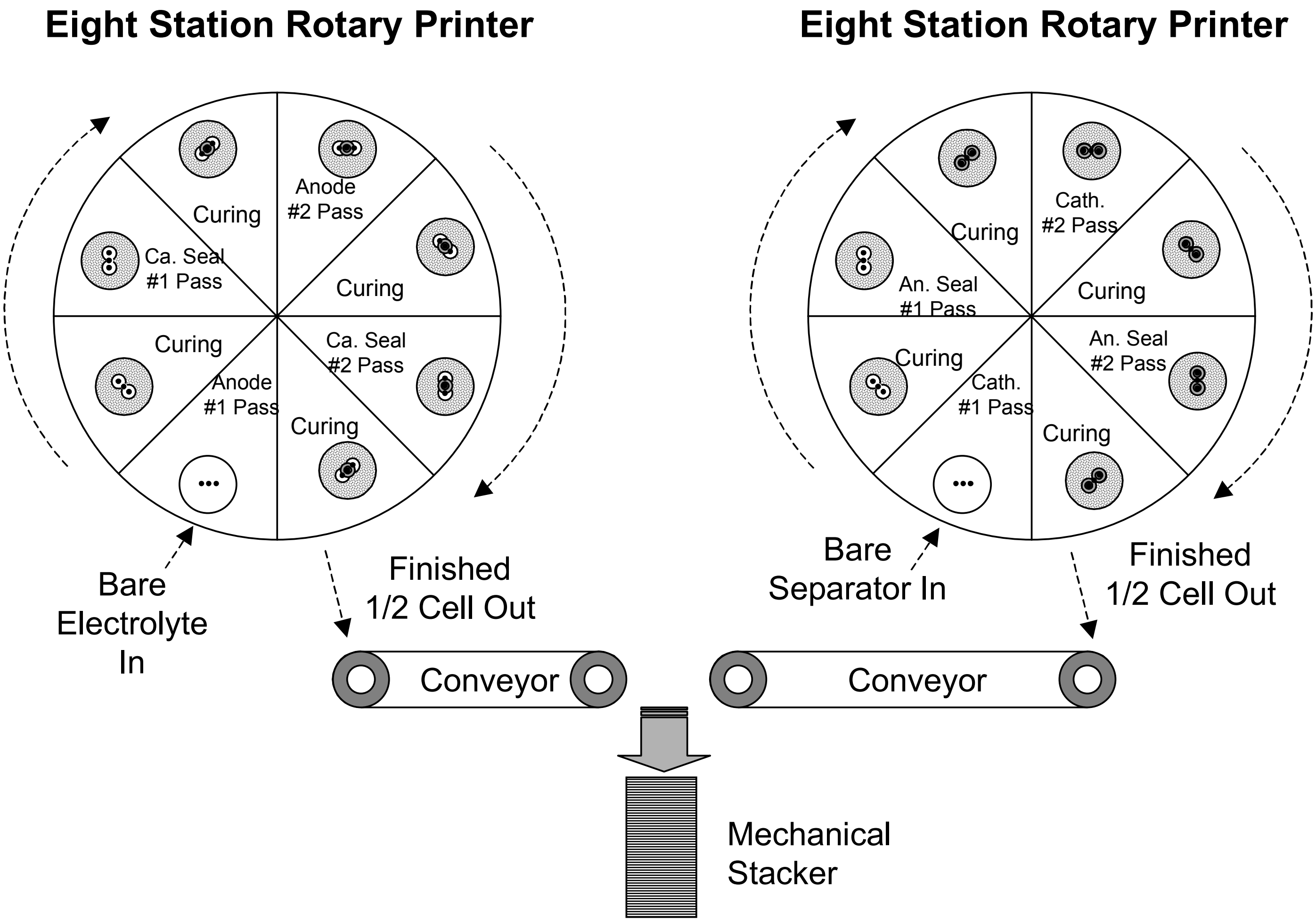

Figure 3. *Example sketch of a mechanized fabrication / stacking process.*

Conclusions

Based on the results and hands-on experience gained from conducting this study, Technology Management, Inc. feels that the impact of using multi-layer-printing technology makes it a highly desirable process and warrants consideration as a viable long-term option for scaled manufacturing of SOFC devices. The economic evaluation indicated that overall a significant reduction in production cost could be achieved. The largest savings were realized by reducing the cost of capital equipment required.