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# Technical cost analysis for PEM fuel cells

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## Abstract

The present cost of fuel cells estimated at about \$200 kW$^{-1}$ is a major barrier for commercialization and use in automotive applications. In the United States the target costs for fuel cell systems for the year 2004 as formulated by PNGV are \$50 kW$^{-1}$. Lomax et al. have estimated the costs of polymer electrolyte membrane (PEM) fuel cells to be as low as \$20 kW$^{-1}$. These estimates are based on careful consideration of high volume manufacturing processes. Recently, Arthur D. Little (ADL) has estimated the cost of a fuel cell system for transportation at \$294 kW$^{-1}$. This estimate considers a fuel processor and directly related balance of plant components. The difference of the cost estimates results from the vastly different design assumptions. Both of these estimates are based on considering a single high volume of production, 500,000 fuel cells per year. This work builds on these earlier estimates by employing the methods of technical cost modeling and thereby including explicit consideration of design specifications, exogenous factor cost and processing and operational details. The bipolar plate is analyzed as a case study. The sensitivity of the costs to uncertainty in process conditions are explored following the ADL design. It is shown that the PNGV targets can only be achieved with design changes that reduce the quantity of material used. This might necessitate a reduction in efficiency from the assumed 80 mpg.

*Keywords:* PEM fuel cell; Technical cost model; Injection molded bi-polar plate

## 1. Introduction

For fuel cells to become commercially successful costs need to be reduced significantly. Cost reduction is expected through the application of high volume manufacturing processes, and two models in the literature have estimated the expected costs for production volumes of 500,000 units per year [1,2]. The cost model by Lomax et al. of Direct Technologies Inc. (DTI) was published in 1998 based on cooperation with Ford Motor company. The Arthur D. Little (ADL) cost model was prepared for the US Department of Energy Transportation Fuel Cell program in 2000. The predicted results differ by more than 500%. In order to use the cost estimates for strategic decisions, it is necessary to gain a better understanding of the cost results. This work reports a comparison of these two models, which differ in the methodology of the cost evaluation, but more significantly differ in their design assumption. A detailed case study of injection molded bipolar plates follows. This case study is based on the ADL design assumptions. The objectives are: (i) to understand the manufacturing cost drivers; (ii) to investigate cost implications of design choices; and (iii) to identify opportunities for cost reduction.

## 2. Background

The two models taken from the literature use process based cost models to estimate the cost of polymer electrolyte membrane (PEM) fuel cells. The DTI model follows a methodology based on the approach by Boothroyd et al. [3]. The ADL report does not specify the methodology used in the cost model but details the cost elements considered in the analysis.

The two models differ significantly in their systems and design assumptions and in the time frame to which the estimate applies as detailed in Table 1. The DTI model assumes that the fuel cell operates on hydrogen while the ADL fuel cell operates on reformate. The DTI model does not consider the fuel efficiency of the system, while the ADL system (fuel cell and reformer) assumes to operate at the 2004 PNGV goals [4] of 80 mpg (2.95 l/100 km). To obtain this goal the ADL model strives to maximize efficiency rather than power with the resulting difference in cell parameters as shown in Table 1. These differences in design assumptions lead to most of the resulting differences in fuel cell component costs as shown in Fig. 1.

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Table 1
Comparison of cost model assumptions

| | Directed technologies Inc. (1998) | Arthur D. Little (2000) |
|---|---|---|
| Time frame | About 5 years | Year 2000 state of the art |
| Operates on | Hydrogen | Reformate |
| Maximizes | Power | Efficiency |
| Stack power (net) | 63 kW | 50 kW |
| Cell characteristics | 0.6 V | 0.8 V |
| Current density | 1076 mA/cm$^2$ | 310 mA/cm$^2$ |
| Active area | 258 cm$^2$ | 600 cm$^2$ |
| Number of cells | 420 | 376 |

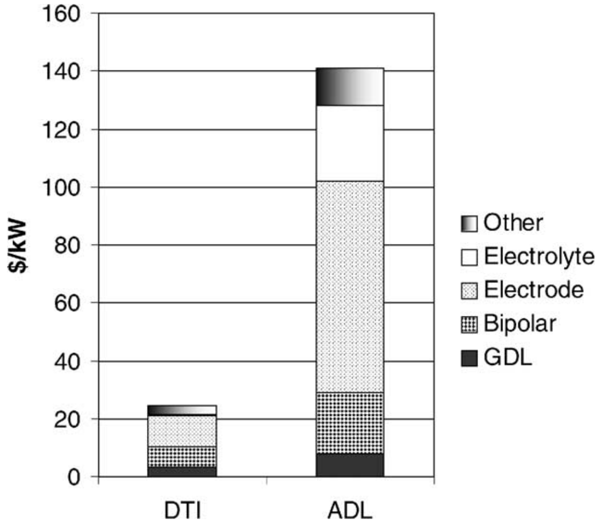

Fig. 1. Comparison of cost model results for fuel cells from the literature: DTI, ADL.

The efficiency assumption in the ADL model requires higher platinum loading in the electrodes (0.8 mg/cm$^2$ for ADL versus 0.2 mg/cm$^2$ for DTI). In addition, the efficiency assumption requires the cell to operate at a point (high voltage, low current density) that leads to the selection of a cell area of 600 cm$^2$ for ADL versus 258 cm$^2$ for DTI. The resulting estimated costs for the electrode are about \$73 kW$^{-1}$ for ADL versus \$10.5 kW$^{-1}$ for DTI. Similarly, the costs of the gas diffusion layer (GDL) and that of the bipolar plate more than double largely due to the larger area. The difference in cost of the membrane stems from a purchase option used by ADL versus a production assumption used by DTI.

The relative cost of the major fuel cell components for both models is shown in Fig. 2. Despite the significant difference in total (and component) cost there are similarities in how the costs are distributed. The cost for the platinum electrode is about 50% of total cost in both cases, with the bipolar plates second in the DTI model and third in the ADL model. The large difference in the cost for the electrolyte membrane stems from the fact that the material used to date is patented, while the DTI model assumes independent production.

For fuel cells to become commercially viable the amount of platinum in the electrodes will need to be reduced as shown for example in the PNGV goals summarized in Fig. 3. Here the electrodes and the membrane constitute only 14% each of the total fuel cell cost of \$35 kW$^{-1}$. The bipolar plates are targeted to cost 29% (\$10 kW$^{-1}$) and represent a significant part of the overall cost. Under these conditions it is critical to understand the cost elements of the bipolar plate in order to achieve the PNGV goal.

### 2.1. Case study: cost model for bipolar plates

For this case study the Alternative Fuel Economics Laboratory (AFEL) used cost models developed at the Materials Systems Laboratory at MIT [5] to evaluate the designs outlined in the reports by DTI and ADL. A technical cost model of metal stamping was used for the design suggested by DTI, and an injection molding cost model was used for the composite plate suggested by DTI, and a composite plate

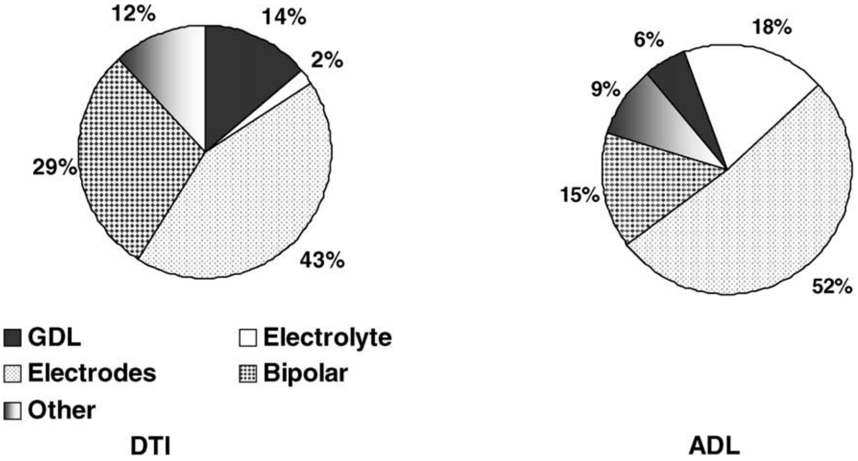

Fig. 2. Relative cost of fuel cell components of the two cost models.

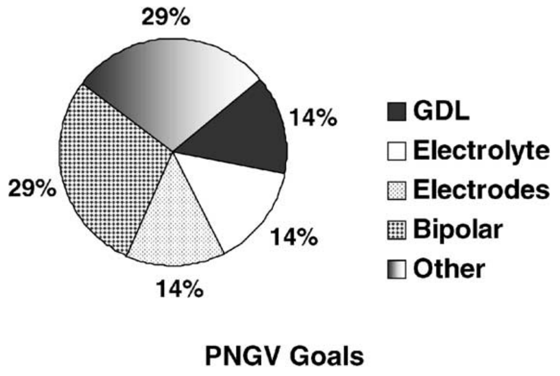

Fig. 3. PNGV target cost breakdown for PEM fuel cell. Total cost target is \$35 $kW^{-1}$.

suggested by ADL. The AFEL results agreed with the DTI and ADL results to within 10% for all three cases.

The AFEL cost model was further employed for a more detailed analysis based on the ADL design using the following design assumptions as a baseline case: production is 500,000 units per year, product life is 5 years; the material is a high purity graphite composite at a materials cost of \$4.65 $kg^{-1}$; there is one cooler cell per bipolar plate and both have the same geometry; the active area of the cell is 600 $cm^2$, and the thickness for manifold and cooler plate is 2.1 mm each or 4.2 mm total. There were no openings for manifolding in this design.

The costs show almost no sensitivity to changes in assumptions for the processing parameters such as die temperature, heat capacity and others within the range of interest. The results were sensitive to production volume and product life as shown in Fig. 4a and b. The differences in cost are due to additional investment in equipment and tooling as the production volume increases and full or partial use of the tool life for product life, respectively. The sensitivity analysis summarized in Fig. 5 shows that there is also some sensitivity to the cycle time. Reducing the cycle time to almost a third of the baseline value would reduce the cost from the baseline cost of \$19.62 to \$18.16 $kW^{-1}$. Here further improvements could be achieved by using molds with two to four cavities. Material cost has the largest effect reducing the cost to \$16.85 $kW^{-1}$ for a 19% decrease in material cost. For the best case (7.5 s cycle time, and \$4 $kg^{-1}$ material cost) the cost of the cell is \$15.34 $kW^{-1}$, which is still far from the PNGV goal of \$10 $kW^{-1}$.

A break up of the total cost of the bipolar cell into cost elements (Fig. 6) shows that materials cost is dominant at about 60% for the DTI design and about 75% for the ADL design. To reach the goal of \$10 $kW^{-1}$ the cost of material needs to be reduced either through a reduction in material unit cost or through a reduction of the amount of material used. This can be accomplished through design changes. The area of the plate could be reduced, which would require an increase in current density, or the plate could be thinner.

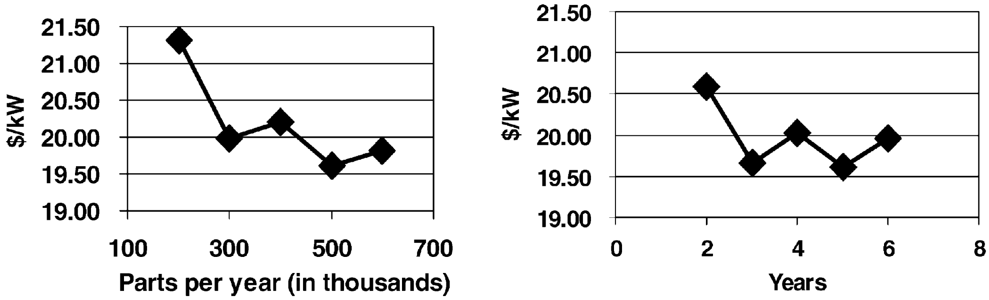

Fig. 4. Manufacturing cost of injection molded bipolar plate for (a) varying production volume and (b) varying product life, based on ADL design.

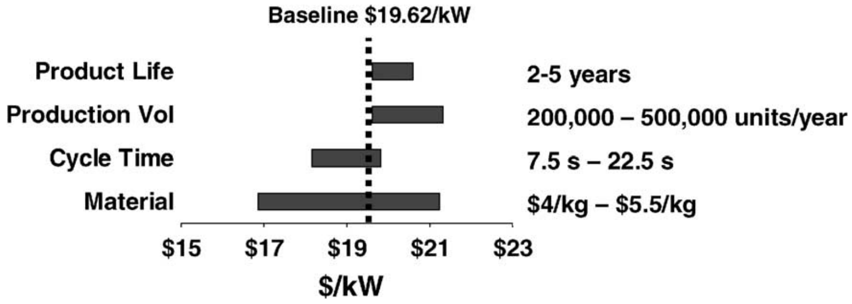

Fig. 5. Sensitivity of cost to manufacturing parameters for baseline conditions: 500,000 units per year, product life is 5 years, material cost is \$4.65 $kg^{-1}$, and plate thickness of 2.1 mm, based on ADL design.

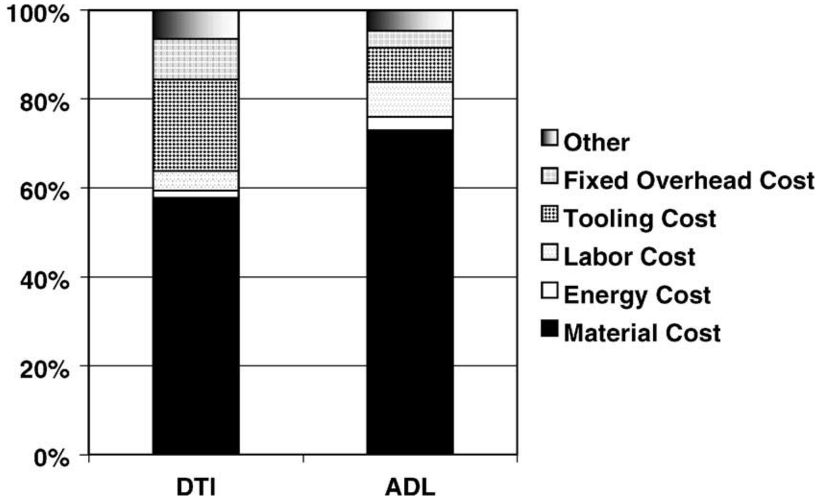

Fig. 6. Cost elements of bipolar plates for two designs: by DTI and ADL.

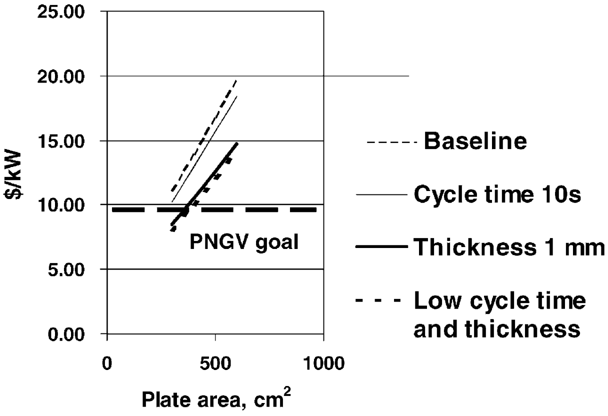

Fig. 7. Cost of bipolar plate (ADL design) versus plate area for four cases: baseline assumptions, reduced cycle time, reduced thickness, reduced cycle time and thickness.

These results are shown in Fig. 7 for the baseline data together with the data for a cycle time of 10 s, a thickness of a single plate of 1 mm (2 mm per cell), and a combination of 10 s cycle time and 1 mm thickness. It can be seen that reducing the thickness is the only strategy that would accomplish the goal of \$10 kW$^{-1}$.

A reduction in plate size would require an increase in current density if the same assumptions of total power of 50 kW$_{\text{net}}$, 300 V total, and fuel efficiency of 80 mpg (2.95 l/100 km) should be retained. This is shown in Fig. 8 for the assumption of 0.7 V/cell and for 0.8 V/cell. For other cell components such as the membrane, the GDL, or the catalyst, material costs dominate the part cost in a similar fashion. For stainless steel bipolar plates without coating materials can cost up to 90% of the total. The cost of these components would similarly be affected by design changes. For a complete consideration of the design implications it would be desirable to have more detailed information on the efficiency

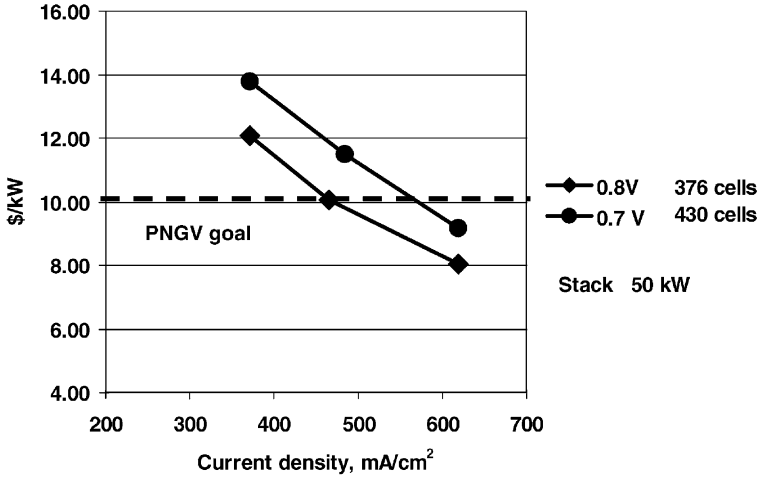

Fig. 8. Cost of bipolar plates versus current density, assuming two operating voltages. Baseline assumptions with 10 s cycle time, and 1 mm thick plate.

of the system as a function of platinum loading or current density.

## 3. Conclusions

Detailed cost models have been applied to two different designs for injection molded bipolar plates made of a graphite-composite and to stamped stainless steel plates. The results agree with those published in the literature within 10%.

The AFEL cost models have been used to study the costs of injection molded bipolar plates in detail in order to explore design changes without the need of costly investments. The results indicate that a cost goal of \$10 $\mathrm{kW}^{-1}$ can be attained. Production volume of about 500,000 units per year will be necessary together with development of tools and materials that facilitate a cycle time of 10 s. Design changes will be required which reduce material cost significantly through changes in plate dimensions.

Since the overall efficiency determines the design of cell components, more information relating efficiencies and cell parameters is required to relate cost and efficiency of the cell.

## Acknowledgements

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