IV.I.4 Cost Analyses of Fuel Cell Stacks/Systems

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Objectives

To develop an independent cost model for proton exchange membrane fuel cell (PEMFC) systems for transportation applications and to assess cost reduction strategies for year 2000 to 2004 development programs.

- To develop an independent cost estimate of PEMFC system costsb including a sensitivity analysis to operating parameters, materials of construction, and manufacturing processes.
- To identify opportunities for system cost reduction through breakthroughs in component and manufacturing technology.
- To provide annual updates to the cost estimate for the duration of the project.

In FY 2004 we focused on the costing of compressed hydrogen storage.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells and Hydrogen Storage sections of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

Component Barriers

- O. Stack Material and Manufacturing Cost

On-Board Hydrogen Storage Barriers – Compressed Gas System

- A. Cost
- B. Weight and Volume
- D. Durability
- I. Materials
- K. Balance-of-Plant (BOP) Components

Approach

- Start with an assessment of compressed gas storage technologies (tanks and BOP), including literature review of compressed gas storage technologies (patents, technical literature, DOE reports), compressed gas applications, tank manufacturing processes, and list of developers and component suppliers.

- Work with Argonne National Laboratory (ANL) to obtain hydrogen requirements for a mid-size hybrid fuel cell vehicle with a range of 370 miles on a combined city/urban drive cycle.
- Develop compressed hydrogen subsystem configuration for critical system components.
- Develop high-volume production cost model including process flows, raw material costs, purchased components, and direct and indirect labor for the tank fabrication.
- Develop preliminary cost estimate and draft report.
- Review with DOE and use as discussion document with tank/system developers.
- Incorporate developer feedback into cost model and prepare final report.
- Update overall fuel cell system cost projection.

Accomplishments

- Completed analysis of compressed hydrogen storage cost and weight and obtained feedback on the assumptions and conclusions from the major developers.

Future Directions

The project under the original award concludes during this fiscal year.

- As more is learned about the degradation mechanisms in PEMFCs, the impact of these factors on component and system costs should be assessed and included in cost projections.
- As technology evolves in high-temperature membranes and hydrogen storage, its influence on system performance and cost should be assessed.
- Overall fuel cell vehicle (FCV) powertrain costs, including the electric motor, regenerative brake systems, power electronics, and hybrid battery cost contributions, should be included in the cost projections and comparisons with internal combustion engine (ICE) powertrain costs.

Introduction

At the outset of the project, five years ago, we focused on the analysis of reformate PEMFC system costs. However, with initiation of the Hydrogen Program, emphasis has shifted to direct hydrogen systems. Consequently, our efforts this year were directed to cost analysis of compressed hydrogen storage technology. Of the hydrogen storage options, high-pressure storage is considered to be nearest commercialization. The other technologies, e.g., chemical hydrides and carbons, entail development of storage systems as well as the materials. Compressed hydrogen storage represents a likely transition technology to demonstrate fuel cell technology in vehicles and to spur early commercialization of fuel cell vehicles (FCVs).

Cost analysis of new technologies provides insights into one potential barrier to commercialization. If the projected costs are too high, the analysis identifies key cost drivers and materials, components, or performance metrics in need of additional R&D. Annual updates of the high volume cost projection provide one metric of the status of PEMFCs for transportation relative to ICE powertrains and DOE program goals.

Approach

We started by developing an understanding of the status of compressed gas (including hydrogen) storage technologies and the balance of plant components needed to integrate the storage tank into the fuel cell system and vehicle. This information was gathered from the literature and through discussions with BOP and carbon fiber suppliers. The composite storage tank drives the system cost, and effort was directed to understanding the tank design rules, properties and cost of available carbon fibers, and manufacturing processes. We then used an available program (netting analysis) to estimate the amount of carbon fiber needed versus the tank dimensions and mechanical properties of the fiber. A manufacturing process flow was then defined and an activities-based cost model constructed with this process and system bill-of-materials. In parallel with this activity, ANL estimated the hydrogen demand for a mid-size hybrid FCV with a range of 370 miles. This hydrogen demand projection established the basis for sizing the capacity of the storage tank.

The model and performance assumptions, baseline cost results, and sensitivity analyses were collected into a draft report to use in discussions of the compressed storage systems. The feedback of the developers was reviewed and the cost projection updated as appropriate. These results along with updated data for the balance of the fuel cell system plant were integrated to assess the state of technology relative to our projections.

Results

Unlike earlier reported reformate system cost analyses, the size of the vehicle, its range, and the drive cycle can have an effect on the cost of the system through the hydrogen demand and the size of the hydrogen storage subsystem. In contrast, the reformer size in reformate systems depended on the scale and operating parameters of the fuel cell, while even though the fuel tank would vary with vehicle size, its cost was insignificant relative to the overall system. The results of the ANL vehicle drive cycle analysis are shown in Table 1 for various hybridization strategies for a 120-kW peak power drive train ranging from a 60- to 120-kW fuel cell. From this range of options, the 80-kW fuel cell/40-kW battery configuration was selected for cost analysis with a hydrogen demand of 5.6 kg and an overall fuel economy of 68 miles per gallon gasoline equivalent (mpgge).

Figure 1 shows the system configuration with tank, valving, regulators, sensors, safety components, and the fill port. Two pressures (5,000 and 10,000 psi) and two high-strength aerospace grade carbon fiber types from Toray (T700S and M30S) were used as a basis for designing and costing the tank. Table 2 shows the weight of the liner, carbon fiber composite, and glass overwrap for the two fiber types and two pressures. Based on this analysis and the

Table 1. Overall System Specification and Storage Requirement

ANL Results	ICEV 120 kW	FC EV 120 kW	FC HEV 100 kW	FC HEV 80 kW	FC HEV 60 kW
Engine/Fuel Cell Power kW Peak	114	120	100	80	60
Battery Power, kW peak	0	0	20	40	55
Fuel Economy, mpgge	23	59	65	68	69
Hydrogen Required	NA	6.3	5.9	5.6	5.6

Source: Dr. Rajesh Ahluwalia, ANL

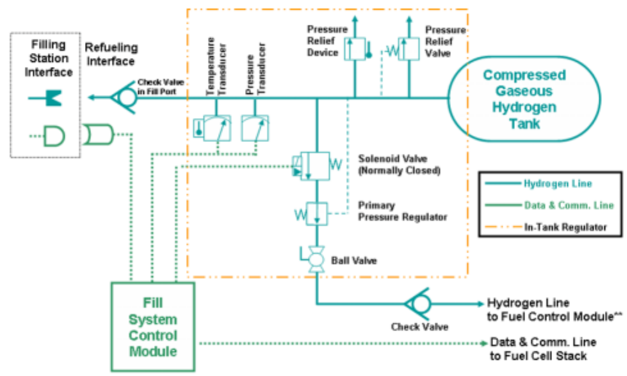

Figure 1. Compressed Hydrogen Sub-System Diagram

cost differential between the two fiber types, the reduction in carbon fiber weight did not justify the higher cost of the M30S fiber. Consequently, T700S fiber was used as the baseline case.

Figure 2 shows the system weight breakdown for the two pressures. We were surprised that the weight of the 10,000 psi system was similar to the lower pressure design (89 versus 83 kg). The smaller diameter of the tank creates the need for less fiber even though the pressure doubles. Figure 3 shows the cost of these systems. Carbon fiber dominates both the weight and the cost of the system. A baseline cost of $10 per lb was assumed for the fiber with a range from $7.50 to $12.50. The carbon fiber industry is relatively mature and we do not expect

Table 2. Tank Design for 5,000 psi and 10,000 psi Pressures and Two Fiber Types

				Tank Component Weight (kg)				
Pressure	**Volume**	**Fiber**	**Liner Type**	**Liner**	**Carbon Fiber Composite**	**Glass Fiber Composite**	**Foam**	**Tank Total**
5,000 PSI	255 Liter	M30S	HDPE	14.4	33.0	5.8	5.9	59
			AL	14.8				
		T700S	HDPE	14.4	37.1	6.6	5.9	64
			AL	14.8				
10,000 PSI	155 Liter	M30S	HDPE	10.3	41.3	7.3	4.7	64
			AL	10.3				
		T700S	HDPE	10.3	46.6	8.2	4.7	70
			AL	10.3				

Carbon Fiber Glass Factor = 0.85; Carbon Fiber Weight % = 68; HDPE thickness = 0.25"; Al thickness = 0.09", Tank weight without bosses and regulator; fiber designations for Toray aerospace high strength grades.

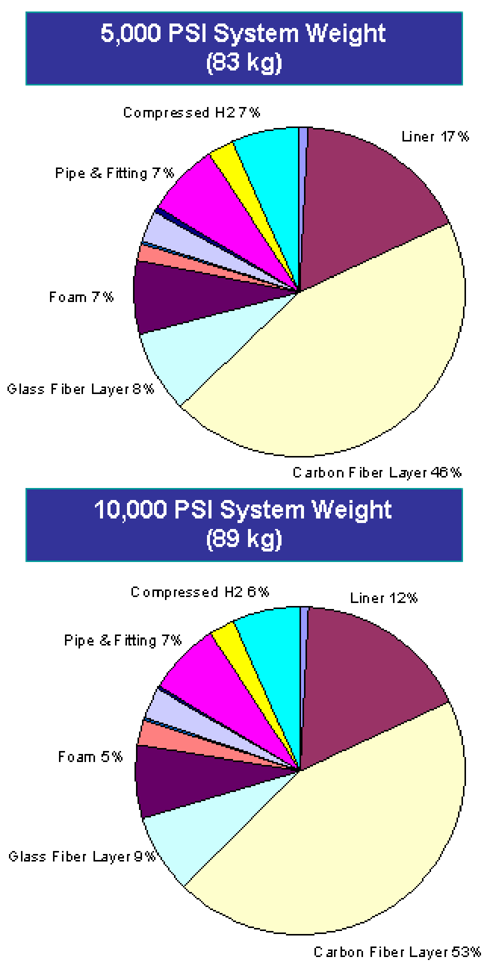

Figure 2. System Weight for the Two Pressures

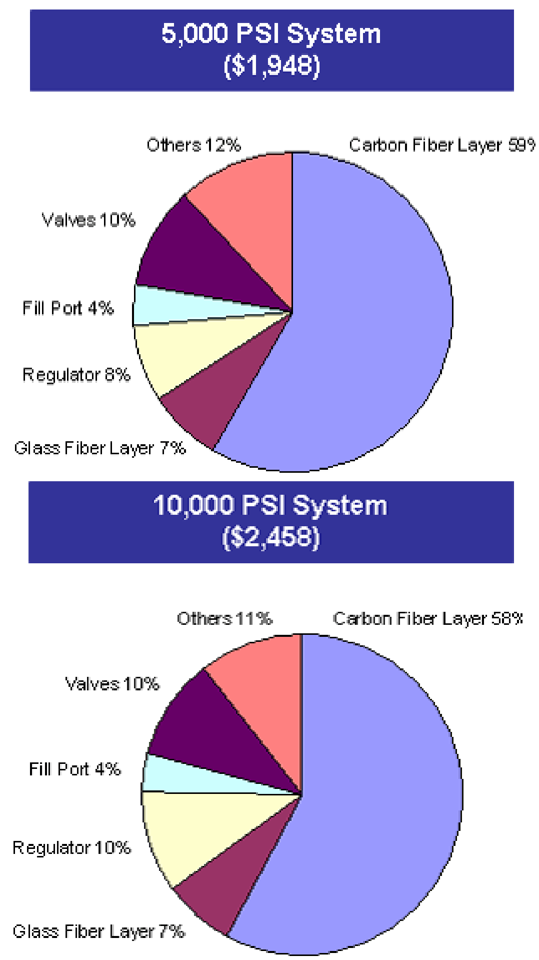

Figure 3. Baseline Cost Estimates for the Two Pressures

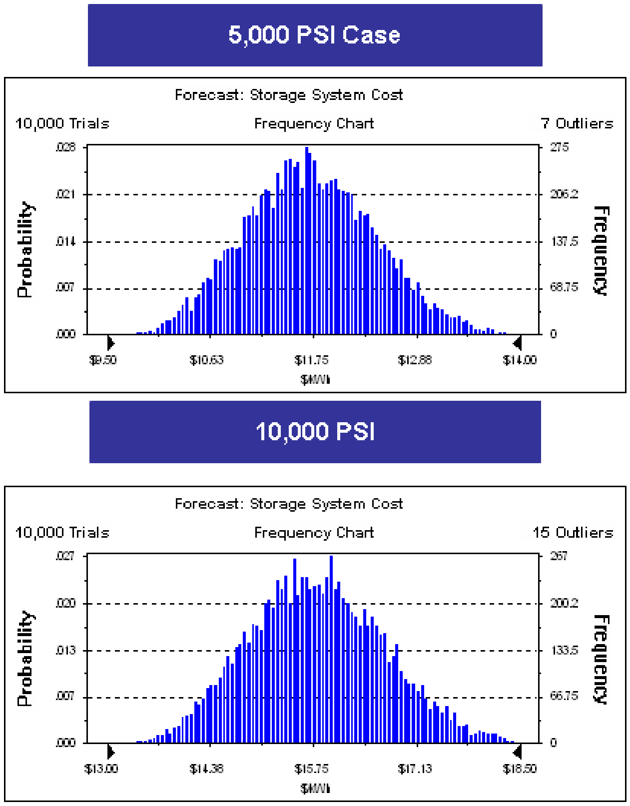

Figure 4. Monte Carlo Simulation of the Uncertainty in the Cost Projection

significant price reductions going forward. Figure 3 shows a similar picture for the hydrogen storage system cost ($1,948 versus $2,458).

Figure 4 shows the Monte Carlo simulation for both pressure cases, and in each case, even the lowest cost does not drop below $10/kWh. Table 3 compares the results of this analysis against the DOE weight and cost targets. The 2010 weight targets are met while a large gap exists between the 2005 volumetric requirements and the model results.

Table 3. Comparison of Model Results with DOE Targets

	DOE Targets			Model Results	
System Metric	2005	2010	2015	5,000 psi	10,000 psi
Cost ($/kWh)	6	4	2	10-16	13-24
Specific Energy (Wt%)	4.5	6	9	6.7	6.3
Energy Density (kWh/liter)	1.2	1.5	2.7	0.6*	0.9*

*Tank volume only

Conclusions

- Based on the projected cost of carbon fiber and the amount of fiber used in the tank, compressed hydrogen storage systems are unlikely to reach DOE targets. Given the large material contribution to the storage system and the maturity of the carbon fiber industry, it unlikely that significant cost reduction can be achieved through material selection.
- The cost of high-strength aerospace grade carbon fiber, a major cost driver, is unlikely to go lower and, consequently, limits the potential for cost reduction.

FY 2004 Publications/Presentations

1. 2004 DOE Hydrogen and Fuel Cell Peer Review, Poster Session (Philadelphia).