Fuel Cell Vehicle Systems Analysis

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Objectives

- Provide DOE and industry with technical solutions and modeling tools that accelerate the introduction of robust fuel cell technologies.
- Quantify benefits and impacts of the Hydrogen, Fuel Cells & Infrastructure Technology (HFC&IT) Program development efforts at the vehicle level (current status evaluation).
- Understand sensitivity of fuel cell technical target values and provide recommendations to DOE technology development managers (future goal evaluation).

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- D. Fuel Cell Power System Benchmarking
- I. Fuel Processor Startup/Transient Operation
- P. Durability
- R. Thermal and Water Management

Approach

- Develop component and vehicle models and link to existing models to enhance systems analysis capabilities.
- Work with industry to apply robust design techniques, optimization tools, and computer-aided engineering (CAE) tools to overcome technical barriers.
- Study benefits of fuel cell system and vehicle design scenarios and transfer to industry.
- Assess impact of various technical team targets at component level.

Accomplishments

- Analyzed and published "Fuel Economy Impacts of Gasoline Reformer Warm-up."
- Integrated two new detailed fuel cell system models into ADVISOR, expanding the range of complexity of modeling capabilities.
- Published technical paper on fuel cell system water management over typical drive schedules.
- Applied robust design methods to fuel cell stack design with Plug Power to understand manufacturing and durability sensitivities.
- Developed Technical Targets Tool for tracking and analyzing the national fuel consumption impacts of DOE research programs.

- Completed initial sensitivity analysis of vehicle fuel economy to fuel cell program technical targets using Technical Targets Tool.

Future Directions

- Perform fuel cell hybrid vehicle system optimization - work with FreedomCAR fuel cell, energy storage, and vehicle systems technical teams to develop energy storage system targets for fuel cell hybrid vehicles.
- Assess sensitivity of fuel consumption to fuel cell technical targets applied across multiple vehicle platforms using Technical Targets Tool.
- Continue water and thermal management analyses for fuel cell vehicles under real driving conditions.
- Transfer robust design techniques to industry to address fuel cell stack cost and durability technical barriers.

Introduction

The Fuel Cell Vehicle Systems Analysis activity at the National Renewable Energy Laboratory is a continuation and expansion of previous efforts in this area. Previous efforts focused on the application of ADVISOR [1], a complete vehicle systems modeling tool, to understanding fuel cell hybrid vehicle design barriers and opportunities. The Office of Hydrogen, Fuel Cells & Infrastructure Technologies has used the simulation results from ADVISOR in the past to assess and revise component and system technical targets. Primary financial support for the development and maintenance of ADVISOR has been through the Office of FreedomCAR and Vehicle Technologies, and the Office of Hydrogen, Fuel Cells & Infrastructure Technologies has been able to leverage this significant investment.

Recent efforts build upon and expand the capabilities of this activity. A new Technical Targets Tool was developed and introduced to automate the technical targets analysis process. It links directly to ADVISOR for vehicle performance estimates and rolls these results up to predict national fuel consumption impacts of DOE research efforts across multiple light-duty vehicle platforms. Additionally, we integrated and applied two new detailed fuel cell system models to understand the water management issues of fuel cell vehicle operation over typical drive cycles. Future studies will include analysis of thermal management characteristics during vehicle operation. Finally, we have developed collaborative relationships with industrial partners and have applied robust design methods to stack and reformer systems to address cost and durability technical barriers.

Approach

It has been our approach to develop component and vehicle models and link them to existing models to enhance our systems analysis capabilities. We work with industry to share and apply robust design techniques, optimization tools, and CAE tools to address the issues of durability, cost, and efficiency. Any results that we derive that are non-proprietary typically form the basis for a publication. Publication and public presentation of our study results have been effective means for transferring knowledge on simulation results and design sensitivities to industry. Finally, we support DOE's effort to set reasonable and challenging technical targets by assessing the impacts of various technical team targets at vehicle system and fleet levels.

Results

Using the existing models in ADVISOR, we estimated the fuel economy impacts on EPA drive cycles of gasoline reformer warm-up. Test data is not yet available as to how long the warm-up process may take or how much energy it may require; however, in our study, we swept the duration and fueling rate over reasonable ranges. We predicted that for long duration and high fueling rates, the fuel consumption for an urban drive cycle could increase by as much as 90% (Figure 1). If the DOE programs are successful in meeting their targets for warm-up, the fuel economy penalty would be 15%-30% in comparison to a hot start fuel cell scenario. In comparison, a typical internal combustion engine (ICE) vehicle incurs a 6%-8% fuel economy penalty for cold-starts. The results of this small study were published at the 2003 Society of Automotive Engineers (SAE) Future Transportation Technologies Conference.

We have also integrated two new fuel cell system models into ADVISOR. The first, a fuel cell model developed by Virginia Tech, based on their contributions to the FutureTruck competition, allows us to model systems with variable pressure operating strategies and performs a complete thermal and water balance on the system. The second is a model developed at the Swedish Royal Institute (KTH). This model is based on the Springer et al. stack model and focuses on complete thermodynamics for the balance of plant system. The models were applied to assess the water balance of a fuel cell hybrid vehicle over typical drive cycles. Results of this study were published at the 2003 American Society of Mechanical Engineers (ASME) First International Conference on Fuel Cell Science, Engineering and Technology.

The results of a study with Plug Power looking at the application of robust design techniques for fuel

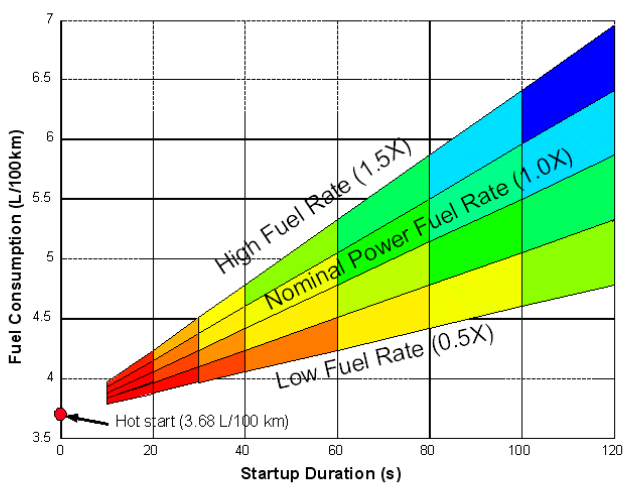

Figure 1. Estimated Fuel Consumption Impact Based on a Range of Startup Durations and Fueling Rates

cell stack design were also published at this same conference. The study reviewed the sensitivity of pressure and pressure distribution within the membrane electrode assembly (MEA) due to variability in mounting bolt loading, MEA thickness, bipolar plate thickness, and material properties (Figure 2). Understanding how tightly these manufacturing variabilities must be controlled is critical to reducing production costs and improving durability.

As a result of our efforts this year, we completed the first version of the Technical Targets Tool. This new tool provides a means for tracking and assessing the impacts of DOE program technical targets. The tool contains a database of technical targets that are applied across multiple vehicle platforms. The tool uses ADVISOR to predict the performance characteristics of vehicles based on the technical targets. A time-based penetration curve and vehicle class specific sales predications are used to estimate the potential fuel consumption savings of the DOE technology programs. Future results are expected to

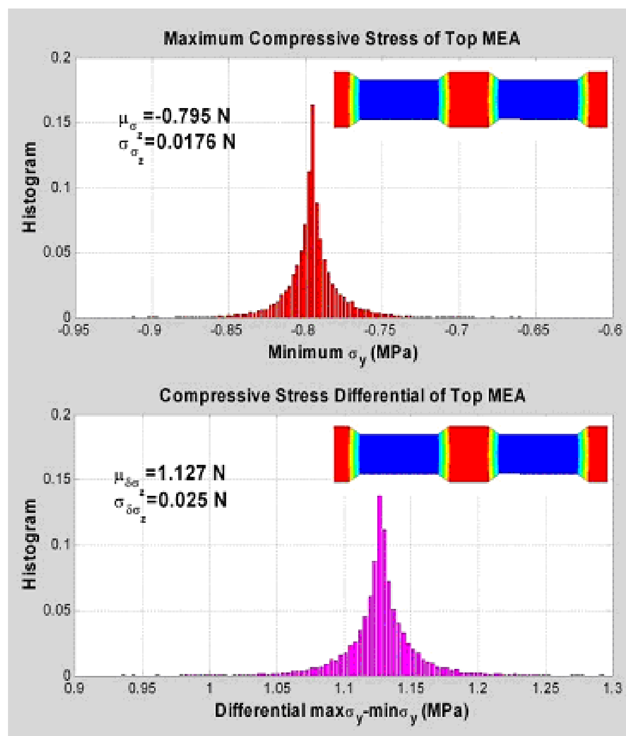

Figure 2. Histograms of maximum maxδ_{ztop} and differential compressive stress $\Delta\delta_{ztop}$ in the top MEA

help ensure that the existing program technical targets lead to applicability across multiple platforms and provide the greatest impact from the DOE efforts.

Conclusions

The following conclusions can be drawn from the Fuel Cell Vehicle Systems Analysis efforts:

- Our analysis showed that the fuel economy impacts of gasoline reformer warm-up may be substantial. The DOE program targets are focused on minimizing this impact.
- Our study on fuel cell system water management over typical drive schedules highlighted capabilities of the new fuel cell system models integrated into ADVISOR. Results of the water balance study showed that condenser and reservoir sizing decisions should consider both the drive cycle requirements and the operating conditions.
- The application of robust design methods to fuel cell stack design provided our industry partner, Plug Power, with a process and a better understanding of the sensitivities that several design variables have on stack pressure distribution. This information could lead to less expensive, more durable fuel cell stacks.
- We demonstrated that the new Technical Targets Tool could be used to predict impacts on national fuel consumption resulting from DOE research program efforts applied across multiple vehicle platforms. As expected, the initial sensitivity results using the Technical Targets Tool indicate the fuel cell system and motor efficiencies have a significant impact on vehicle fuel economy.

FY 2003 Publications/Presentations

1. Markel, Tony; Wipke, Keith; Haraldsson, Kristina; Kelly, Ken; Vlahinos, Andreas. "Fuel Cell Vehicle Systems Analysis." Presented at Hydrogen, Fuel Cells and Infrastructure Technologies Annual Program Review. Berkeley, CA. May 20-23, 2003.

2. Wipke, K. B.; Markel, A.; Haraldsson, K.; Davis, P. "Predicting the Fuel Economy Impact of "Cold-Start" for Reformed Gasoline Fuel Cell Vehicles." SAE Publication 2003-01-2253. Presented at SAE Future Transportation Technologies Conference. Costa Mesa, CA. June 23-25, 2003.

3. Markel, Tony; Zolot, Matthew; Wipke, Keith B.; Pesaran, Ahmad A. "Energy Storage System Requirements for Hybrid Fuel Cell Vehicles." 3rd International Advanced Automotive Battery Conference. Nice, France. June 10-13, 2003.

4. Haraldsson, Kristina; Markel, Tony; Wipke, Keith. "An Analysis Of Water Management for a PEM Fuel Cell System in Automotive Drive Cycles." ASME First International Conference on Fuel Cell Science, Engineering and Technology. Rochester, New York. April 21-23, 2003.

5. Willis, Gordon; Weller, Rick; Wipke, Keith. "An Engineering System for Automated Design and Optimization of Fuel Cell Powered Vehicles." ASME First International Conference on Fuel Cell Science, Engineering and Technology. Rochester, New York. April 21-23, 2003.

6. Vlahinos, Andreas; Kelly, Kenneth; D'Aleo, Jim; Stathopoulos, Jim. "Effect of Material and Manufacturing Variations on Membrane Electrode Assembly Pressure Distribution." ASME First International Conference on Fuel Cell Science, Engineering and Technology. Rochester, New York. April 21-23, 2003.

7. Kelly, Kenneth; Vlahinos, Andreas; Rodriguez, Pablo; and Bharathan, Desikan. "Innovative Thermal Management of Fuel Cell Power Electronics." ASME First International Conference on Fuel Cell Science, Engineering and Technology. Rochester, New York. April 21-23, 2003.

8. Haraldsson, Kristina; Wipke, Keith. "An Evaluation of Select PEM Fuel Cell System Models." The 202nd Electrochemical Society Symposium. Salt Lake City, Utah. October 23, 2002.

9. Markel, Tony; Wipke, Keith; Nelson, Doug. "Vehicle System Impacts of Fuel Cell System Power Response Capability." SAE Publication 2002-01-1959. Presented at FutureCar Congress. June, 2002.

References

1. Markel, T., Brooker, A., Hendricks, T., Johnson, V., Kelly, K., Kramer, B., O'Keefe, M., Sprik, S., Wipke, K., "ADVISOR: a systems analysis tool for advanced vehicle modeling" Journal of Power Sources Volume 110, Issue 2, 22 August 2002, pp. 255-266.